SMITHSONIAN

CONTRIBUTIONS TO KNOWLEDGE.

VOL. XV.

EVERY MAN IS A VALUABLE MEMBER OF SOCIETY, WHO, BY HIS OBSERVATIONS, RESEARCHES, AND EXPERIMENTS, PROCURES KNOWLEDGE FOR MEN.—SMITHSON.

CITY OF WASHINGTON:
PUBLISHED BY THE SMITHSONIAN INSTITUTION.
MDCCCLXVII.

ADVERTISEMENT.

THIS volume forms the fifteenth of a series, composed of original memoirs on different branches of knowledge, published at the expense, and under the direction, of the Smithsonian Institution. The publication of this series forms part of a general plan adopted for carrying into effect the benevolent intentions of JAMES SMITHSON, Esq., of England. This gentleman left his property in trust to the United States of America, to found, at Washington, an institution which should bear his own name, and have for its objects the "*increase* and *diffusion* of knowledge among men." This trust was accepted by the Government of the United States, and an Act of Congress was passed August 10, 1846, constituting the President and the other principal executive officers of the general government, the Chief Justice of the Supreme Court, the Mayor of Washington, and such other persons as they might elect honorary members, an establishment under the name of the "SMITHSONIAN INSTITUTION FOR THE INCREASE AND DIFFUSION OF KNOWLEDGE AMONG MEN." The members and honorary members of this establishment are to hold stated and special meetings for the supervision of the affairs of the Institution, and for the advice and instruction of a Board of Regents, to whom the financial and other affairs are intrusted.

The Board of Regents consists of three members *ex officio* of the establishment, namely, the Vice-President of the United States, the Chief Justice of the Supreme Court, and the Mayor of Washington, together with twelve other members, three of whom are appointed by the Senate from its own body, three by the House of Representatives from its members, and six persons appointed by a joint resolution of both houses. To this Board is given the power of electing a Secretary and other officers, for conducting the active operations of the Institution.

To carry into effect the purposes of the testator, the plan of organization should evidently embrace two objects: one, the increase of knowledge by the addition of new truths to the existing stock; the other, the diffusion of knowledge, thus increased, among men. No restriction is made in favor of any kind of knowledge; and, hence, each branch is entitled to, and should receive, a share of attention.

The Act of Congress, establishing the Institution, directs, as a part of the plan of organization, the formation of a Library, a Museum, and a Gallery of Art, together with provisions for physical research and popular lectures, while it leaves to the Regents the power of adopting such other parts of an organization as they may deem best suited to promote the objects of the bequest.

After much deliberation, the Regents resolved to divide the annual income into two parts—one part to be devoted to the increase and diffusion of knowledge by means of original research and publications—the other part of the income to be applied in accordance with the requirements of the Act of Congress, to the gradual formation of a Library, a Museum, and a Gallery of Art.

The following are the details of the parts of the general plan of organization provisionally adopted at the meeting of the Regents, Dec. 8, 1847.

DETAILS OF THE FIRST PART OF THE PLAN.

I. To increase Knowledge.—*It is proposed to stimulate research, by offering rewards for original memoirs on all subjects of investigation.*

1. The memoirs thus obtained, to be published in a series of volumes, in a quarto form, and entitled "Smithsonian Contributions to Knowledge."

2. No memoir, on subjects of physical science, to be accepted for publication, which does not furnish a positive addition to human knowledge, resting on original research; and all unverified speculations to be rejected.

3. Each memoir presented to the Institution, to be submitted for examination to a commission of persons of reputation for learning in the branch to which the memoir pertains; and to be accepted for publication only in case the report of this commission is favorable.

4. The commission to be chosen by the officers of the Institution, and the name of the author, as far as practicable, concealed, unless a favorable decision be made.

5. The volumes of the memoirs to be exchanged for the Transactions of literary and scientific societies, and copies to be given to all the colleges, and principal libraries, in this country. One part of the remaining copies may be offered for sale; and the other carefully preserved, to form complete sets of the work, to supply the demand from new institutions.

6. An abstract, or popular account, of the contents of these memoirs to be given to the public, through the annual report of the Regents to Congress.

II. To increase Knowledge.—*It is also proposed to appropriate a portion of the income, annually, to special objects of research, under the direction of suitable persons.*

1. The objects, and the amount appropriated, to be recommended by counsellors of the Institution.

2. Appropriations in different years to different objects; so that, in course of time, each branch of knowledge may receive a share.

3. The results obtained from these appropriations to be published, with the memoirs before mentioned, in the volumes of the Smithsonian Contributions to Knowledge.

4. Examples of objects for which appropriations may be made:—

(1.) System of extended meteorological observations for solving the problem of American storms.

(2.) Explorations in descriptive natural history, and geological, mathematical, and topographical surveys, to collect material for the formation of a Physical Atlas of the United States.

(3.) Solution of experimental problems, such as a new determination of the weight of the earth, of the velocity of electricity, and of light; chemical analyses of soils and plants; collection and publication of articles of science, accumulated in the offices of Government.

(4.) Institution of statistical inquiries with reference to physical, moral, and political subjects.

(5.) Historical researches, and accurate surveys of places celebrated in American history.

(6.) Ethnological researches, particularly with reference to the different races of men in North America; also explorations, and accurate surveys, of the mounds and other remains of the ancient people of our country.

I. To diffuse Knowledge.—*It is proposed to publish a series of reports, giving an account of the new discoveries in science, and of the changes made from year to year in all branches of knowledge not strictly professional.*

1. Some of these reports may be published annually, others at longer intervals, as the income of the Institution or the changes in the branches of knowledge may indicate.

2. The reports are to be prepared by collaborators, eminent in the different branches of knowledge.

3. Each collaborator to be furnished with the journals and publications, domestic and foreign, necessary to the compilation of his report; to be paid a certain sum for his labors, and to be named on the title-page of the report.

4. The reports to be published in separate parts, so that persons interested in a particular branch, can procure the parts relating to it, without purchasing the whole.

5. These reports may be presented to Congress, for partial distribution, the remaining copies to be given to literary and scientific institutions, and sold to individuals for a moderate price.

The following are some of the subjects which may be embraced in the reports:—

I. PHYSICAL CLASS.

1. Physics, including astronomy, natural philosophy, chemistry, and meteorology.
2. Natural history, including botany, zoology, geology, &c.
3. Agriculture.
4. Application of science to arts.

II. MORAL AND POLITICAL CLASS.

5. Ethnology, including particular history, comparative philology, antiquities, &c.
6. Statistics and political economy.
7. Mental and moral philosophy.
8. A survey of the political events of the world; penal reform, &c.

III. LITERATURE AND THE FINE ARTS.

9. Modern literature.
10. The fine arts, and their application to the useful arts.
11. Bibliography.
12. Obituary notices of distinguished individuals.

II. TO DIFFUSE KNOWLEDGE.—*It is proposed to publish occasionally separate treatises on subjects of general interest.*

1. These treatises may occasionally consist of valuable memoirs translated from foreign languages, or of articles prepared under the direction of the Institution, or procured by offering premiums for the best exposition of a given subject.

2. The treatises to be submitted to a commission of competent judges, previous to their publication.

DETAILS OF THE SECOND PART OF THE PLAN OF ORGANIZATION.

This part contemplates the formation of a Library, a Museum, and a Gallery of Art.

1. To carry out the plan before described, a library will be required, consisting, 1st, of a complete collection of the transactions and proceedings of all the learned societies of the world; 2d, of the more important current periodical publications, and other works necessary in preparing the periodical reports.

2. The Institution should make special collections, particularly of objects to verify its own publications. Also a collection of instruments of research in all branches of experimental science.

3. With reference to the collection of books, other than those mentioned above, catalogues of all the different libraries in the United States should be procured, in order that the valuable books first purchased may be such as are not to be found elsewhere in the United States.

4. Also catalogues of memoirs, and of books in foreign libraries, and other materials, should be collected, for rendering the Institution a centre of bibliographical knowledge, whence the student may be directed to any work which he may require.

5. It is believed that the collections in natural history will increase by donation, as rapidly as the income of the Institution can make provision for their reception; and, therefore, it will seldom be necessary to purchase any article of this kind.

6. Attempts should be made to procure for the gallery of art, casts of the most celebrated articles of ancient and modern sculpture.

7. The arts may be encouraged by providing a room, free of expense, for the exhibition of the objects of the Art-Union, and other similar societies.

8. A small appropriation should annually be made for models of antiquity, such as those of the remains of ancient temples, &c.

9. The Secretary and his assistants, during the session of Congress, will be required to illustrate new discoveries in science, and to exhibit new objects of art; distinguished individuals should also be invited to give lectures on subjects of general interest.

In accordance with the rules adopted in the programme of organization, each memoir in this volume has been favorably reported on by a Commission appointed

for its examination. It is however impossible, in most cases, to verify the statements of an author; and, therefore, neither the Commission nor the Institution can be responsible for more than the general character of a memoir.

The following rules have been adopted for the distribution of the quarto volumes of the Smithsonian Contributions:—

1. They are to be presented to all learned societies which publish Transactions, and give copies of these, in exchange, to the Institution.

2. Also, to all foreign libraries of the first class, provided they give in exchange their catalogues or other publications, or an equivalent from their duplicate volumes.

3. To all the colleges in actual operation in this country, provided they furnish, in return, meteorological observations, catalogues of their libraries and of their students, and all other publications issued by them relative to their organization and history.

4. To all States and Territories, provided there be given, in return, copies of all documents published under their authority.

5. To all incorporated public libraries in this country, not included in any of the foregoing classes, now containing more than 10,000 volumes; and to smaller libraries, where a whole State or large district would be otherwise unsupplied.

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[1] Each memoir is separately paged and indexed.

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AN INVESTIGATION OF THE ORBIT OF NEPTUNE, WITH GENERAL TABLES OF ITS MOTION.

BY
SIMON NEWCOMB,
PROFESSOR OF MATHEMATICS, UNITED STATES NAVY.

[ACCEPTED FOR PUBLICATION, MAY, 1865.]

COMMISSION

TO WHICH THIS PAPER HAS BEEN REFERRED.

Admiral C. H. Davis, U. S. N.
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CHAPTER I.

INTRODUCTION.

THE errors of the published ephemerides of Neptune are now increasing very rapidly. In 1863, Walker's ephemeris was in error by 33″, and Kowalski's by 22″. Both ephemerides may be 5′ in error before the end of the present century. The orbit of this planet is, therefore, more uncertain than that of any other of the larger members of our system. The uncertainty arises from the insufficiency of the data at the command of those astronomers who have hitherto investigated the motions of this planet. These motions are so slow that it is impossible to determine the elements of the orbit with accuracy from observations extending through only a few years. In Walker's investigations the errors of observation are multiplied more than a hundred times in the elements deduced from them, on account of the smallness of the arc through which the planet had moved.

The time has now come when the orbit can be determined with some approach to accuracy. The planet has moved through an arc of nearly 40° since its discovery, and the errors of observation will be multiplied only ten or twelve times in the errors of the elements. In commencing the work of a revision of the theory of Neptune, it will be well to glance at the past and present state of our knowledge on this subject.

Approximate elements of this planet, neglecting the effect of perturbations, were computed by several astronomers within a year or two after its discovery. But the work of preparing a theory which should include the perturbations produced by all the other planets seems to have been left entirely in the hands of Professor Peirce and Mr. Sears C. Walker.

§ 2. All the first approximations to the elements showed that the mean motion was very nearly half that of Uranus. It was, therefore, for some time doubtful whether the mutual action of the two planets might not be such as to render the period of Neptune exactly double that of Uranus, and thus present us, on a much grander scale, with a phenomenon similar to that exhibited by the satellites of Jupiter. Professor Peirce's first perturbations of Neptune were computed on this hypothesis, and published in the Monthly Notices of the Royal Astronomical Society, Vol. VIII, p. 40. The eccentricity of Neptune was neglected, but that of the disturbing planets was included in the perturbations.

With these perturbations, the ancient observations of Lalande, and the vast number of modern observations made in nearly every active observatory in the world during 1846 and 1847, Mr. Walker computed his "Elliptic Elements I." of

Neptune. The longitude of perihelion referred to the mean Equinox of Jan. 1, 1847, eccentricity, and mean daily motion were as follows:

$$\pi = 48^\circ\ 21'\ 2''.93$$
$$e = .00857741.$$
$$n = 21''.55448.$$

This mean motion rendered it certain that the supposed relation between the mean motions of the planets Uranus and Neptune had no foundation in fact. Professor Peirce thereupon revised his theory, and published the new perturbations in the Proceedings of the American Academy, Vol. I, p. 286.

The near approach to commensurability of the mean motions renders the general theory of the mutual action of Uranus and Neptune extremely complex. Twice the mean motion of the latter exceeds that of the former by only 320″ according to Walker, or 304″ according to my first revision of his elements. The terms in the perturbations which contain this very small quantity as a divisor will, therefore, be very large. Considered as perturbations of the elements, their period will be more than 4000 years. We have an analogous instance in the 900 year equation of Jupiter and Saturn. But in the latter case the perturbations of the mean motion are of the *third* order with respect to the eccentricities and inclinations, while in Uranus and Neptune they are of the first order. From this circumstance it happens that, notwithstanding the smaller masses of the disturbing planets, the perturbation of the mean motion is as great in the case of the planets in question as in that of Jupiter and Saturn, and that of the other elements enormously greater. In fact, the perihelion of Neptune oscillates through a space of *eight degrees* in consequence of the terms in question. Such a perturbation as this, four degrees on each side of the mean, is, I think, found nowhere else in our system. Moreover, a change of 1″ in the mean motion of the planet will produce a change of nearly 2′ in the coefficient of this perturbation. Any attempt to determine its magnitude with accuracy will, therefore, be hopeless.

But the difficulties connected with these terms can be avoided in the case of a theory which is designed to be exact for a period of only a few centuries. Notwithstanding the great magnitude of the general integrals of the perturbations, if we take these integrals between limits not exceeding a couple of centuries, we shall find them so small as not to involve serious difficulty. Their effect on the co-ordinates can then be developed in powers of the time, and the values thus obtained will not be subject to any uncertainty of moment. This is substantially the course adopted by Professor Peirce. He says of the terms in question:

"These coefficients will vary very sensibly by a change in the value of the mean motion of Neptune, arising from a more accurate determination of its orbit. But the principal effect of these terms can for a limited period, such as a century, for instance, be included in the ordinary forms of elliptic motion, and the residual portion will assume a secular form which is no more liable to change from a new correction of the mean motion of Neptune than the other small coefficients of the equations of perturbations."

Accordingly, subducting from the terms in question a series of expressions

which would result from arbitrary changes in the elliptic orbit, there is left a small residual, mostly developed in powers of the time, and only amounting to a few seconds in a century, which alone is retained.

With the new perturbations, and revised normal places of Neptune, Mr. Walker obtained the following final set of elements, which he denominated Elliptic Elements II.:

$$\begin{aligned}
\pi &= 47^\circ\ 12'\ \ 6''.50\\
\Omega &= 130\ \ \ 4\ \ 20\ .81\\
\varepsilon &= 328\ \ 32\ \ 44\ .20\\
i &= 1\ \ 46\ \ 58\ .97.\\
e &= .00871946.\\
\mu &= 21''.55448.
\end{aligned}$$

Epoch, Jan.1, 1847.

From these elements and perturbations we have a continuous ephemeris of Neptune since the time of its optical discovery. From 1846 till 1851 inclusive, this ephemeris is found in the Appendix to Vol. II of the Smithsonian Contributions to Knowledge; for 1852, in Vol. III of the same series, and also in the Astronomical Journal; and for subsequent years, in the American Ephemeris and Nautical Almanac.

All the modern observations on which these elements were founded were made in the years 1846–47, while the planet was moving over an arc of only two and a half degrees. Considering that the complete determination of the elements requires, effectively, four observed longitudes, all in different parts of the orbit, and that three of these positions are included in a space of less than three degrees, it must be admitted that an accurate determination of the elements was, under the circumstances, impossible, owing to the imperfections of the observations. As already remarked, the errors of observation would be multiplied several hundred times in the elements. Hence, with the best possible observations, the elements would be uncertain by one or more minutes. But the observations themselves were mainly differential ones; and it is very doubtful whether the positions of the stars of comparison were as well determined as the position of the planet itself could be determined by a series of good meridian observations.

§ 3. The theory of Neptune was next taken up by Professor Kowalski, of the University of Kasan. His work was published under the title of "*Recherches sur les mouvements de Neptune, suivées des tables de cette planète,* Kasan, 1855." The long-period perturbations of the elements are here developed, in their general form, as perturbations of the co-ordinates. There are, therefore, a much larger number of terms having large coefficients in this theory than in that of Professor Peirce.

Owing to this change in the form of the perturbations, the two theories cannot be directly compared. But the ephemerides resulting from each theory can be compared directly with observation, and corrections of the elements thence obtained. It is thus found that the elements in question require, approximately, the following corrections in order that the ephemerides may agree with observations to 1863:

	Theory of Walker.	Theory of Kowalski.
$\delta\pi$	$-4^\circ\ 11'\ ''$	$-4^\circ\ 12'\ ''$
δe	$-0\ \ 0\ 52$	$-0\ \ 0\ 51$
$\delta\varepsilon$	$-0\ \ 3\ \ 6$	$-\ \ 2\ 53$
δn	$-\ \ 8.4$	$-\ \ 8.5$

Thus, it seems that the theory of Kowalski is, on the whole, no nearer the truth than that of Walker, although it was founded on observations up to 1853, when the planet had moved through an arc of sixteen degrees since its optical discovery.* The cause of this failure to derive a more accurate result is an accidental mistake in the computation of the perturbations of the radius vector by Jupiter, as I have more fully pointed out in the Monthly Notices of the Royal Astronomical Society for December, 1864.

§ 4. The form which Professor Kowalski finds his equations of condition to assume is illustrative of an interesting and important principle of the method of least squares. By the comparison of his provisional theory with observations, forty-four equations of condition are obtained for the corrections of the four elements π, e, ε, and n. It is then inquired whether it is possible to determine the orbit of Neptune from the modern observations alone, omitting that of Lalande, the planet having moved through an arc of sixteen degrees. Treating the equations derived from the modern observations alone by the method of least squares, four normal equations are obtained. Two of these equations are, omitting the terms involving the correction of the mass of Uranus, which we do not need,

$$-10.4994\,\delta n - 21.2661\,\delta\varepsilon + 13.0088\,e\delta\pi + \ \ 40.2211\,\delta e = -324''.65,$$
$$26.9661\,\delta n - 73.2702\,\delta\varepsilon + 40.2211\,e\delta\pi + 139.9967\,\delta e = -886\ .63,$$

and the other two can be transformed into the following:

$$-10.4994\,\delta n - 21.2661\,\delta\varepsilon + 13.0073\,e\delta\pi + \ \ 40.2219\,\delta e = -324.50,$$
$$-26.9661\,\delta n - 73.2702\,\delta\varepsilon + 40.2219\,e\delta\pi + 140.0009\,\delta e = -886.77.$$

It will be seen that the last two equations are very nearly identical with the first two. Hence it is concluded that the modern observations alone give only two independent relations between the four unknown quantities sought, and do not suffice, therefore, to determine the elements of Neptune.

Now, the identity in question does not prove that the modern observations are insufficient to determine the elements, because *it is the necessary result of the mode of treating equations of the kind in question by the method of least squares.* This can be most easily shown by a theorem in determinants. By the elementary principle of determinants, if we have a number of linear equations between the same number of unknown quantities, of the form

* The differences of the two values of $\delta\pi$ and δe, which are so small, do not correctly represent the absolute differences of the two theories, owing to the great difference of longitude of perihelion in the two theories proceeding from the different forms given to the perturbations. The real difference Kowalski—Walker is given by the equations

$$\delta.e \sin\pi = +\ \ 1'',$$
$$\delta.e \cos\pi = -13.$$

$$\begin{array}{llll} a_1x + b_1y + c_1z + \text{etc.} & \ldots\ldots & = n_1, \\ a_2x + b_2y + c_2z + \text{etc.} & \ldots\ldots & = n_2, \\ \text{etc.} \quad \text{etc.} \quad \text{etc.} \quad \text{etc.} & & \text{etc.}; \end{array}$$

each unknown quantity is given in the form

$$x = \frac{A_1}{R} n_1 + \frac{A_2}{R} n_2 + \frac{A_3}{R} n_3 + \text{etc.},$$

in which R represents the determinant formed from all the coefficients a, b, etc. in the given equations, and A_1, A_2, etc. the partial determinants, obtained by omitting column a, row 1, column a, row 2, etc.

If, now, the number of equations is greater than that of the unknown quantities, and they are solved by the method of least squares, the form of the solution will be the same as the above, except that for R will be substituted the sum of the squares of all the determinants R, formed by solving separately every combination of such number of the given equations as is equal to the number of unknown quantities, and for A_1, A_2, etc., certain powers and products of the partial determinants which enter into the separate solutions. Hence, if these determinants are very small, the corresponding determinants in the solution by least squares will be very small quantities of the second order. But the determinants will all be very small if the equations are nearly equivalent to a number less than that of the unknown quantities; that is, if they can be put into the form

$$\begin{array}{r} X = n_1, \\ Y = n_2, \\ Z = n_3, \\ \alpha X + \beta Y + \gamma Z + \text{etc.} + \rho = n_4, \\ \alpha' X + \beta' Y + \gamma' Z + \text{etc.} + \rho' = n_5, \\ \text{etc.} \quad \text{etc.} \quad \text{etc.} \quad \text{etc.} \quad \text{etc.} \quad \text{etc.}; \end{array}$$

the quantities X, Y, Z, etc. being less in number than the unknown quantities, and ρ being a very small linear function of the unknown quantities. If the ρ's vanish, all the determinants will vanish with it; whence, if they are very small, the determinants will be very small likewise. Calling a system of equations identical when they really give fewer independent relations than there are unknown quantities, the theorem sought may be expressed as follows:

If a system of equations differ from identity by a very small quantity, the normal equations derived from them will be identical to small quantities of the second order.

Hence, if such a system of equations is to be solved by least squares, it will be necessary to carry the solution to nearly twice as many decimals as are necessary in the original coefficients. Thus, in the case under consideration, as Professor Kowalski considered it necessary to retain four places of decimals in the coefficients of the unknown quantities, it would have been necessary to include at least six or seven decimals in the normal equations, instead of only four.

But the necessity for so long a numerical calculation can be avoided by a suitable transformation of the equations of condition. If the equations are identical, they really give certain linear functions of the unknown quantities less in number

than the unknown quantities. We may then substitute these linear functions themselves in place of an equal number of the unknown quantities. If the equations are not absolutely identical, the coefficients of the other unknown quantities will not entirely vanish by the substitution, and thus we shall still have the whole number of unknown quantities, only the coefficients of certain of them will be very small. The solution by least squares can then be performed without trouble, because the extra decimals will be necessary only in multiplying by the very small coefficients, when they can be introduced with ease. Afterward the values of the original unknown quantities can be deduced from those of the linear functions, and the unknown quantities which have been retained.

Suppose, for example, that the equations of condition are

$$\begin{aligned}
a_1x + b_1y + c_1z &= n_1\\
a_2x + b_2y + c_2z &= n_2\\
a_3x + b_3y + c_3z &= n_3\\
a_4x + b_4y + c_4z &= n_4\\
\cdot\quad\ \cdot\quad\ \cdot\ &\quad\ \cdot\\
\cdot\quad\ \cdot\quad\ \cdot\ &\quad\ \cdot\\
\cdot\quad\ \cdot\quad\ \cdot\ &\quad\ \cdot\\
a_nx + b_ny + c_nz &= n_n
\end{aligned}$$

A simple inspection, or, at least, an attempt to solve three of the most diverse of the equations, will show if the given n equations are really equivalent to only one or two. Then we should put

$$\begin{aligned}
X &= \alpha x + \beta y + \gamma z\\
Y &= \alpha' x + \beta' y + \gamma' z
\end{aligned}$$

the coefficients α, β, γ, being entirely arbitrary, and so taken that when X and Y were substituted for x and y the coefficients of z should be as small as possible. It would conduce to simplicity if α and β', or α' and β, could each be made zero, which could always be done.

If we attempt to correct the elements of a planet's orbit by observations extending over only a few degrees, the equations of condition will necessarily be of the kind referred to. Hence a transformation of this kind will be advisable. An example will be given in the correction of the orbit of Neptune from observation.

§ 5. Ten years have elapsed since the publication of Kowalski's theory, and no general revision of the orbit has been published by any astronomer, so far as the writer is aware. The observations which have accumulated in the mean time would seem sufficient to fix the elements exactly enough to give the place of the planet within 5″ during the remainder of the present century. It is, therefore, proposed,

1. To determine the elements of the orbit of Neptune with as much exactness as a series of observations extending through an arc of forty degrees will admit of.

2. To inquire whether the mass of Uranus can be concluded from the motions of Neptune.

3. To inquire whether those motions indicate the action of an extra-Neptunian planet, or throw any light on the question of the existence of such a planet.

4. To construct general tables and formulæ by which the theoretical place of Neptune may be found at any time, and, more particularly, at any time between the years 1600 and 2000.

In giving the steps of an investigation like this, the true end should be to furnish the means whereby every step can be corrected, or verified if already correct, and to start only from admitted data. Sometimes a result will necessarily depend, to a certain extent, on an act of judgment, as in assigning relative values to different determinations of the same element. In this case data should be given for a revision of the judgment, as far as this may be thought desirable.

Such, with very few exceptions, is the rule adhered to in the present paper. The data are the published volumes of astronomical observations, and the fundamental formulæ of celestial mechanics. The steps will nearly or quite always be so short that any one may be verified from the preceding one without much labor.

The author is indebted to the courtesy of the Astronomer Royal, of the late Captain James M. Gilliss, and of Professor G. W. Hough, for the observations made at Greenwich, Washington, and Albany in the years 1863 and 1864, which have added greatly to the reliableness of the results of his investigation.

WASHINGTON, April, 1865.

CHAPTER II.

PROVISIONAL THEORY OF NEPTUNE.

§ 6. All the perturbations have been computed by formulæ founded on the method of La Grange; the development of the perturbative function in series, and the variation of arbitrary constants.

The following notation is used:

l = mean longitude.

λ = mean longitude, counted from ascending node of inner planet on outer one.

ϕ = inclination of orbit to the ecliptic.

γ = mutual inclination of two orbits to each other.

α = ratio of the mean distances.

$u = \sin \frac{1}{2} \gamma$.

f = mean anomaly.

ω = distance of the perihelion from the ascending node of the inner planet on the outer one.

For the other elements the almost universal notation of astronomers is adopted. The elements which pertain to the outer planet (Neptune) are distinguished by an accent.

The potential of the disturbing force exerted by one planet upon another, usually called the perturbative function, may be developed into an infinite series of terms, each of which shall be of the form

$$m \frac{h}{a'} \cos (i'\lambda' + i\lambda + j'\omega' + j\omega)$$

in which i, i', j, and j' are numerical coefficients. h is a function of the ratio of the mean distances, the eccentricities, and the mutual inclination of the orbits.

Then, by the theory of the variation of arbitrary constants, any term of the perturbative function in the action of an inner on an outer planet will cause the following differential variations of the four elements which determine the form of the orbit, and the position of the planet in it. Putting

$$i'\lambda' + i\lambda + j'\omega' + j\omega = N,$$
$$e = \sin \psi,\ g = \cos \psi \tan \tfrac{1}{2} \psi;$$

we have

$$\begin{aligned}
\frac{da'}{dt} &= -2\, m i' h a' n' \sin N, \\
\frac{d\varepsilon'}{dt} &= m n' \left\{ g' \frac{dh}{de'} + 2\, h + 2\, \alpha \frac{dh}{d\alpha} \right\} \cos N, \qquad (1) \\
\frac{de'}{dt} &= m n' h \left\{ j' \cot \psi' + i' g' \right\} \sin N, \\
\frac{d\pi'}{dt} &= m n' \cot \psi' \frac{dh}{de'} \cos N.
\end{aligned}$$

From the first equation and the relation between the mean distance and mean motion, we obtain

$$\frac{dn'}{dt} = 3\, m'n'^2\, i'h \sin N.$$

These equations are entirely rigorous, provided that we regard the elements in the second member as variable. But they can be integrated only by successive approximations. In a first approximation the elements are regarded as constant Equations similar to (1) for the elements of all the planets whose action is taken into account being integrated in this way, the resulting values may be substituted in the second members of (1), and a new integration be performed.

In the case of Neptune, however, the variations of the elements are so slow that a single approximation will be amply sufficient for a period of several centuries, provided that we adopt suitable values of the elements in the second members; that is, if we add such constants to the integrals that the latter shall be very small for the present time. Putting $\nu = \frac{n'}{i'n' + in'}$,

we shall have, on the supposition that the elements as they enter into the second member are constant,

$$\begin{aligned} \log a' &= m\nu A \cos N + a'_0,\ e' = m\nu E \cos N + e'_0, \\ l' &= m\nu L \sin N + n'_0 t + \varepsilon'_0,\ \pi' = m\nu W \sin N + \pi'_0, \end{aligned} \tag{2}$$

$A, L, E,$ and W being given by the equations

$$\begin{aligned} A &= 2\, i'h, \\ L &= -3\, i'\nu h + 2\, h + 2\, \alpha \frac{dh}{d\alpha} + g \frac{dh}{de'}, \\ E &= -h\, (j' \cot \psi' + i'g'), \\ W &= \cot \psi' \frac{dh}{de'}. \end{aligned} \tag{3}$$

a'_0, n'_0 ε', e'_0, and π'_0 are arbitrary constants, dependent on the position and velocity of the planet at a given epoch. a_0 and n_0 are, however, dependent on each other.

For the perturbations of the true longitude in orbit, and the logarithm of the radius vector, we shall have, omitting accents,

$$\begin{aligned} \delta v = \delta l & \\ + m\nu \{ eL - eW - E \} \sin (N - f) & \quad - \tfrac{1}{8} e^2 m\nu \{ eL - eW - 3E \} \sin (N - f) \\ + m\nu \{ eL - eW - E \} \sin (N + f) & \quad - \tfrac{1}{8} e^2 m\nu \{ eL - eW + 3E \} \sin (N + f) \\ + \tfrac{5}{4} em\nu \{ eL - eW - E \} \sin (N - 2f) & \quad - \text{ etc.} \\ + \tfrac{5}{4} em\nu \{ eL - eW + E \} \sin (N + 2f) & \\ + \tfrac{13}{8} e^2 m\nu \{ eL - eW - E \} \sin (N - 3f) & \\ + \tfrac{13}{8} e^2 m\nu \{ eL - eW + E \} \sin (N + 3f) & \\ + \tfrac{103}{48} e^3 m\nu \{ eL - eW - E \} \sin (N - 4f) & \\ + \quad \text{etc.} & \end{aligned} \tag{4}$$

$$
\begin{aligned}
\delta \log r = \delta \log a \\
&+ mv\{2\,i'h + \tfrac{1}{2}eE - \tfrac{1}{8}e^3E\}\cos N && - \tfrac{3}{16}e^2mv\{eL - eW - 3E\}\cos(N-f) \\
&+ \tfrac{1}{2}mv\{eL - eW - E\}\cos(N-f) && + \tfrac{3}{16}e^2mv\{eL - eW + 3E\}\cos(N+f) \\
&- \tfrac{1}{2}mv\{eL - eW + E\}\cos(N+f) && - \text{etc.} \\
&+ \tfrac{3}{4}emv\{eL - eW - E\}\cos(N-2f) && \qquad (5) \\
&- \tfrac{3}{4}emv\{eL - eW + E\}\cos(N+2f) \\
&+ \tfrac{17}{16}e^2mv\{eL - eW - E\}\cos(N-3f) \\
&- \text{etc.}
\end{aligned}
$$

By these formulæ all the perturbations of the longitude and radius vector have been computed, except that the computation was so conducted as to reject all terms above a certain order with respect to the eccentricities. The sum of all the factors (functions of the ratio of the mean distance) of any power of the eccentricity in any coefficient in the perturbations of the co-ordinates will generally be much smaller than each individual factor, as we shall presently show. If, for example, we have

$$\delta v = e^2\,(f + f' + f'')\sin N$$

the sum $f + f' + f''$ will, in general, nearly destroy itself, being much smaller than the individual components, f, f', and f''. Hence, if the computation is arranged so as to include any one of the f's, it should include all. This end may be attained by omitting from h, its differential coefficients, and $h\cot\psi$, all terms of a higher order with respect to the eccentricities than the assigned limit. Thus, h being of the form

$$h = e'^s\,(\varkappa_1 + e'^2\varkappa_2 + e'^4\varkappa_4 + \ldots\}$$

if we limit ourselves to the power $s+1$, we should put

$$
\begin{aligned}
& h = e'^s\varkappa_1;\ \alpha\frac{dh}{d\alpha} = e'^s\alpha\frac{d\varkappa_1}{d\alpha}; \\
& \frac{dh}{de'} = se'^{s-1}\varkappa_1 + (s+2)\,e'^{s+1}\varkappa_2 \\
& sh\cot\psi = se'^{s-1}\varkappa_1 + se'^{s+1}(-\tfrac{1}{2}\varkappa_1 + \varkappa_2).
\end{aligned}
$$

§ 7. *Perturbations of latitude.*

The equations which determine the change in the plane of a planet's orbit are

$$
\begin{aligned}
\frac{d\theta'}{dt} &= \frac{a'n'}{\sin\phi'\cos\psi'}\cdot\frac{dR}{d\phi'} \\
\frac{d\phi'}{dt} &= -\frac{a'n'}{\sin\phi'\cos\psi'}\cdot\frac{dR}{d\theta'}
\end{aligned}
\qquad (6)
$$

R being a function of λ, λ', ω, ω', and γ, each of which depends on the position of the plane of the orbit, we have

$$
\begin{aligned}
\frac{dR}{d\phi'} &= \frac{dR}{d\lambda}\frac{d\lambda}{d\phi'} + \frac{dR}{d\omega}\frac{d\omega}{d\phi'} + \frac{dR}{d\lambda'}\frac{d\lambda'}{d\phi'} + \frac{dR}{d\omega'}\frac{d\omega'}{d\phi'} + \frac{dR}{d\gamma}\frac{d\gamma}{d\phi'} \\
\frac{dR}{d\theta'} &= \frac{dR}{d\lambda}\frac{d\lambda}{d\theta'} + \frac{dR}{d\omega}\frac{d\omega}{d\theta'} + \frac{dR}{d\lambda'}\frac{d\lambda'}{d\theta'} + \frac{dR}{d\omega'}\frac{d\omega'}{d\theta'} + \frac{dR}{d\gamma}\frac{d\gamma}{d\theta'}
\end{aligned}
$$

The values of the second of each pair of differential coefficients can easily be determined geometrically. λ, ω, λ', etc., it will be remembered, represent the distance of certain points on each orbit from the ascending node of the disturbing planet on the disturbed one: the infinitesimal changes in those quantities, produced by infinitesimal changes in the position of the plane of either orbit, will be due entirely to the changes in the position of that node. Let us put

$\varkappa' =$ distance of common node from ascending node of disturbed planet on the ecliptic.

$\varkappa =$ same quantity for disturbing planet.

By drawing the diagram, it will readily be seen that by a change in ϕ' the common node will be moved forward on the disturbed planet by the amount

$$+ \sin \varkappa' \cot \gamma d\phi',$$

and on the disturbing planet by the amount

$$+ \sin \varkappa' \operatorname{cosec} \gamma d\phi',$$

while γ will be varied by the amount

$$- \cos \varkappa' d\phi'.$$

In like manner, by a change in θ', the corresponding changes will be

$$\begin{aligned} &- \cos \varkappa' \sin \phi' \cot \gamma d\theta', \\ &- \cos \varkappa' \sin \phi' \operatorname{cosec} \gamma d\theta', \\ &- \sin \varkappa' \sin \phi' d\theta'. \end{aligned}$$

We therefore have

$$\begin{aligned} &\frac{d\lambda'}{d\phi'} = \frac{d\omega'}{d\phi'} = - \sin \varkappa' \cot \gamma, \\ &\frac{d\lambda}{d\phi'} = \frac{d\omega}{d\phi'} = - \sin \varkappa' \operatorname{cosec} \gamma, \\ &\frac{1}{\sin \phi'} \frac{d\lambda'}{d\theta'} = \frac{1}{\sin \phi'} \frac{d\omega'}{d\theta'} = \cos \varkappa' \cot \gamma, \\ &\frac{1}{\sin \phi'} \frac{d\lambda}{d\theta'} = \frac{1}{\sin \phi'} \frac{d\omega}{d\theta'} = \cos \varkappa' \operatorname{cosec} \gamma, \\ &\frac{d\gamma}{d\phi'} = - \cos \varkappa'; \ \frac{1}{\sin \phi'} \frac{d\gamma}{d\theta'} = - \sin \varkappa'. \end{aligned}$$

Also, by the differentiation of the representative term of R,

$$\begin{aligned} &\frac{dR}{d\lambda'} = - \frac{mi'h}{a'} \sin N, \quad \frac{dR}{d\omega'} = - \frac{mj'h}{a'} \sin N, \\ &\frac{dR}{d\lambda} = - \frac{mih}{a'} \sin N, \quad \frac{dR}{d\omega} = - \frac{mjh}{a'} \sin N, \\ &\frac{dR}{d\gamma} = \frac{dR}{du} \frac{du}{d\gamma} = \tfrac{1}{2} \frac{m}{a'} \frac{dh}{du} \cos \tfrac{1}{2} \gamma \cos N. \end{aligned}$$

Substituting these expressions for the differential coefficients in the values of

$$\frac{dR}{d\phi'} \text{ and } \frac{dR}{d\theta'}, \text{ we have}$$

$$\frac{dR}{d\phi'} = \frac{m}{a'} h \sin x' \sin N \{ (i'+j') \cot \gamma + (i+j) \operatorname{cosec} \gamma \} - \tfrac{1}{2} \frac{m}{a'} \frac{dh}{du} \cos \tfrac{1}{2}\gamma \cos x' \cos N.$$

$$\frac{1}{\sin \phi} \frac{dR}{d\theta} = -\frac{m}{a'} h \cos x' \sin N \{ (i'+j') \cot \gamma + (i+j) \operatorname{cosec} \gamma \} - \tfrac{1}{2} \frac{m}{a'} \frac{dh}{du} \cos \tfrac{1}{2}\gamma \sin x' \cos N.$$

Let us now put

$$i'+j'+i+j = -\iota.$$

It may be remarked that ι will then be the coefficient of the longitude of the common node of the orbits in the usual development of the perturbative function. The above equations may then be put into the form

$$\frac{dR}{d\varphi'} = -\frac{m}{a'} \iota h \operatorname{cosec} \gamma \sin x' \sin N - \frac{m}{a'} (i'+j') h \tan \tfrac{1}{2}\gamma \sin x' \sin N - \tfrac{1}{2} \frac{m}{a'} \frac{dh}{du} \cos \tfrac{1}{2}\gamma \cos x' \cos N.$$

$$\frac{1}{\sin \varphi} \frac{dR}{d\theta'} = \frac{m}{a'} \iota h \operatorname{cosec} \gamma \cos x' \sin N + \frac{m}{a'} (i'+j') h \tan \tfrac{1}{2}\gamma \cos x' \sin N - \tfrac{1}{2} \frac{m}{a'} \frac{dh}{du} \cos \tfrac{1}{2}\gamma \sin x' \cos N.$$

Substituting these expressions in (6), and integrating, we shall have the values of $\delta\theta'$ and $\delta\phi'$, the perturbations of the inclination and node.

For the perturbations of the latitude, counted in the direction perpendicular to the plane of the orbit, we shall have

$$\begin{aligned} \delta\beta' &= \delta\phi' \sin (v' - \theta') - \sin \phi' \delta\theta' \cos (v' - \theta') \\ &= m\nu \sec \psi' \{ T + I \} \sin (N + V) \\ &\quad + m\nu \sec \psi' \{ T - I \} \sin (N - V) \end{aligned} \qquad (7)$$

Where

$$T = \tfrac{1}{4} \frac{dh}{du} \cos \tfrac{1}{2}\gamma; \quad I = \tfrac{1}{4} h \{ \iota \operatorname{cosec} \gamma + (i'+j') \tan \tfrac{1}{2}\gamma \}$$

$V =$ true distance of planet from common node.

Putting

$$B_1 = T + I; \qquad B_2 = T - I,$$

and developing V in terms of λ and f to terms of the second order with respect to the eccentricity, we shall have

$$\delta\beta = m\nu B_1 \begin{pmatrix} (1 - e'^2) \sin (N + \lambda) \\ + \ e' \sin (N + \lambda + f) \\ - \ e' \sin (N + \lambda - f) \\ + \tfrac{9}{8} e'^2 \sin (N + \lambda + 2f) \\ - \tfrac{1}{8} e'^2 \sin (N + \lambda - 2f) \end{pmatrix} + m\nu B_2 \begin{pmatrix} (1 - e'^2) \sin (N - \lambda) \\ + \ e' \sin (N - \lambda - f) \\ - \ e' \sin (N - \lambda + f) \\ + \tfrac{9}{8} e'^2 \sin (N - \lambda - 2f) \\ - \tfrac{1}{8} e'^2 \sin (N - \lambda + 2f) \end{pmatrix} \quad (8)$$

For the perturbations of the constants which determine the position of the orbit, we put

$$p = \sin\phi \sin\theta; \qquad q = \sin\phi\cos\theta;$$

$$\tau = \text{longitude of common node of the two orbits.}$$

We then have

$$\delta p' = 2\,mv\,\{I \sin\tau\cos N - T\cos\tau\sin N\};$$

$$\delta q' = 2\,mv\,\{I\cos\tau\cos N + T\sin\tau\sin N\}. \tag{9}$$

Or,

$$\delta p' = \;\; mv\,\{(I-T)\sin(N+\tau) - (I+T)\sin(N-\tau)\};$$

$$\delta q' = \;\; mv\,\{(I-T)\cos(N+\tau) + (I+T)\cos(N-\tau)\};$$

§ 8. The equations (2) and (9) determine the periodic perturbations of the elements. For the secular variations, which proceed from those terms of the perturbative in which both i' and i are zero, the same expressions apply, only changing

$$v\sin N \text{ into } \quad n't\cos N;$$

$$v\cos N \text{ into } -n't\sin N.$$

We therefore have, for the secular variations,

$$\frac{dl'}{dl} = \quad mn'\,L_0\,\cos N;$$

$$\frac{de'}{dt} = -\,mn'\,E_0\,\sin N;$$

$$\frac{d\pi'}{dt} = \quad mn'\,W_0\cos N; \tag{10}$$

$$\frac{dp'}{dt} = -\,2\,mn'\,\{I_0\sin\tau\sin N + T_0\cos\tau\cos N\};$$

$$\frac{dq'}{dt} = -\,2\,mn'\,\{I_0\cos\tau\sin N - T_0\sin\tau\cos N\}.$$

Owing to the smallness of the eccentricity of Neptune, it will be advisable to substitute the rectangular co-ordinates of the centre of its orbit for the eccentricity and longitude of perihelion. The perihelion itself is subject to changes so great that it would otherwise be necessary to develop the perturbations to quantities of a higher order than the first. We shall, therefore, put

$$h = e\sin\pi; \qquad k = e\cos\pi.$$

For the secular variations of h and k, we then have, to a sufficient degree of approximation,

$$\frac{dh}{dt} = \quad mn'\,e'W_0\cos(N+\pi');$$

$$\frac{dk}{dt} = -\,mn'\,e'W_0\sin(N+\pi'). \tag{11}$$

§ 9. *Development of the action of an inner on outer planet through the Sun.*

The perturbations which one planet produces on another may be divided into two distinct parts.

1. Those produced by their direct attraction on each other.

2. Those produced by the displacement of the Sun by the attraction of the disturbing planet. The co-ordinates of the disturbed planet being counted from the centre of the Sun, the displacement of the Sun not only changes the value of the co-ordinates by changing their origin, but also by modifying the attraction of the Sun itself.

The perturbations of both classes may be included in the same formulæ, and the total perturbations computed in the same way that those of the first class are, by a very simple modification of those functions of the ratio of the mean distances which enter into the different values of h. But in the case of the action of an inner on an outer planet more than twice as far from the Sun, this method will be subject to this serious inconvenience; that the perturbations of the elements are many times greater than those of the co-ordinates. Referring to formulæ (4) and (5), it will be remembered that L, E, and W really express perturbations of the mean longitude, perihelion, and eccentricity, and it will be seen that the perturbations of the true longitude δv are expressed as a function of the perturbations of those elements. Now, having in this way computed the perturbations of any co-ordinate which depend upon the different terms of the perturbative function, when we collect those coefficients which are multiplied by the sine or cosine of identical angles, we shall frequently find that their sum will nearly vanish, as has been already remarked. As this circumstance depends on a theorem of some importance, which will furnish a valuable check on the developments we shall presently give, it is worth while to trace it to its origin.

The elements of a planet depend on its *position* and its *velocity* at a given epoch; each element is a function of the co-ordinates, their differential coefficients, and the time, or, representing an element by a, and putting, for shortness,

$$\xi = \frac{dx}{dt}, \eta = \frac{dy}{dt}, \zeta = \frac{dz}{dt},$$

we have six equations of the form

$$a_n = f(x, y, z, \xi, \eta, \zeta, t) \tag{12}$$

When we express the co-ordinates as a function of the elements and the time, we have

$$x, y, \text{ or } z = f(a_1, a_2, a_3, a_4, a_5, a_6, t) \tag{13}$$

Substituting for the elements the values just given, ξ, η, and ζ must vanish identically in the value of each co-ordinate. If, now, the changes in ξ, η, and ζ are of a higher order of magnitude than those in x, y, and z, the co-ordinates will be subject to smaller variations than the elements.

Suppose, now, that one of the co-ordinates is affected with an inequality of which the period is very short compared with that of the revolution of the planet. Represent it by

$$c \sin (pnt + \varepsilon).$$

Its differential coefficient will be

$$pnc \cos (pnt + \varepsilon).$$

Since the *elements* contain this coefficient, and therefore include terms in which the large number p multiplies the coefficient of the angle, their perturbations will be much larger than that of the co-ordinate. But, in passing from the perturbations of the elements to those of the co-ordinates, these large terms must destroy each other.

Let us apply this principle to the case under consideration. That portion of the perturbative function which arises from the action of an inner planet on the Sun may be developed in a series of terms of the form

$$\frac{mc}{a'a^2} \cos (i'\lambda' + i\lambda + C);$$

c representing a number, not a line.

It therefore becomes infinite when a is infinitely small.

The second differential coefficient of the perturbation of any rectilineal co-ordinate of the outer planet will be of the order of magnitude

$$\frac{dR}{da'} = \frac{mc}{a^2} \cos N,$$

putting

$$N = i'\lambda' + i\lambda + C.$$

If we integrate this differential, and develop the quantity $\frac{c}{i'n' + in}$ according to the powers of $\frac{n'}{n} = \frac{a^{\frac{3}{2}}}{a'^{\frac{3}{2}}}$, the largest terms in the first differential coefficient of the co-ordinates will be of the form

$$\frac{mc}{ia^{\frac{1}{2}}} \sin N.$$

This also will become infinite when a is infinitely small; and since the perturbations of the elements contain these terms, it follows that they also will be infinite in this case. Finally, by another integration, we shall have for the largest perturbations of the co-ordinate itself

$$\frac{mca}{i^2} \cos N,$$

which will vanish when a is infinitely small. Hence, in the case under consideration, *although the perturbations of the elements become infinite, those of the co-ordinates vanish.*

The co-ordinates referred to are linear. The order of magnitude of the angular co-ordinates, or the logarithms of any linear co-ordinate, will be given by dividing by a'. We shall, therefore, have for largest term in the perturbations

$$\delta v,\ \delta\beta, \text{ or } \delta \log r = mca \begin{matrix}\sin\\ \cos\end{matrix} N.$$

Hence, when we collect the perturbations of the co-ordinates due to the cause in question, all terms of a higher order of magnitude than this ought to destroy each other identically.

§ 10. That portion of the perturbative function which is due to the action of the inner planet on the sun is

$$\frac{r'}{r^2} \cos V$$

V being the angular distance between the planets. Developing it in a series of terms of the form

$$\frac{mh}{a'} \cos (i'\lambda' + i\lambda + j'\omega' + j\omega)$$

h will be of the form $\frac{c}{a^2}$, c being a numerical coefficient, multiplied by powers of the eccentricities and mutual inclinations.

From this development, and the equations (3), (4), (5), (7), and (8), I have computed the following analytical values of the coefficients for the perturbations of the longitude, latitude, and logarithm of radius vector.

$$\begin{aligned}
\delta v \quad &= \frac{m}{\alpha^2} \Sigma\, V^{(i)} \sin N^{(i)} \\
\delta \log r &= \frac{m}{\alpha^2} \Sigma\, R^{(i)} \cos N^{(i)} \\
\delta \beta \quad &= \frac{m}{\alpha^2} \Sigma\, B^{(i)} \sin N^{(a)}
\end{aligned} \tag{16}$$

$$\begin{aligned}
V^{(1)} &= (1 - u^2 - \tfrac{1}{2} e^2)\,(3\nu_1^2 + 2\nu_1 + 3\nu_4 + \nu_5) \\
&\quad + e'^2\,(- \tfrac{3}{2}\nu_1^2 - \tfrac{1}{2}\nu_1 + 3\nu_5^2 - 2\nu_5 - \tfrac{5}{8}\nu_{12} + \tfrac{15}{8}\nu_{13}) \\
V^{(2)} &= ee'\,(6\nu_2^2 + \tfrac{3}{2}\nu_2 + 6\nu_3^2 - 3\nu_3 + 3\nu_8 + \tfrac{15}{2}\nu_{11}) \\
V^{(3)} &= e\,(- 6\nu_3^2 + 4\nu_3 - 2\nu_2 - 6\nu_{11}) \\
V^{(4)} &= e'\,(- 3\nu_1^2 - \tfrac{1}{2}\nu_1 - \tfrac{9}{4}\nu_4 - \tfrac{5}{4}\nu_5 + \tfrac{1}{2}\nu_{12}) \\
V^{(5)} &= e'\,(3\nu_1^2 + \tfrac{3}{2}\nu_1 + 3\nu_5^2 + \tfrac{3}{4}\nu_5 + \tfrac{15}{4}\nu_4 + \tfrac{3}{2}\nu_{13}) \\
V^{(9)} &= e^2\,(\tfrac{27}{8}\nu_6 - \tfrac{81}{8}\nu_9^2 + \tfrac{27}{4}\nu_9 - \tfrac{81}{8}\nu_{16}) \\
V^{(10)} &= e^2\,(- \tfrac{3}{8}\nu_7 + \tfrac{3}{8}\nu_{10}^2 + \tfrac{1}{4}\nu_{10} + \tfrac{1}{8}\nu_{17}) \\
V^{(11)} &= ee'\,(- \tfrac{5}{2}\nu_2 - 6\nu_3^2 + \nu_3 - \tfrac{9}{2}\nu_{11} + \nu_{18}) \\
V^{(12)} &= e'^2\,(- \tfrac{15}{4}\nu_1^2 - \tfrac{5}{8}\nu_1 - \tfrac{21}{8}\nu_4 - \tfrac{13}{8}\nu_5 + \tfrac{3}{8}\nu_{12}^2 + \tfrac{1}{8}\nu_{12} + \tfrac{1}{4}\nu_{19}) \\
V^{(13)} &= e'^2\,(\tfrac{15}{4}\nu_1^2 + \tfrac{15}{8}\nu_1 + \tfrac{39}{8}\nu_4 + 3\nu_5^2 + \tfrac{5}{8}\nu_5 + \tfrac{27}{8}\nu_{13}^2 + \tfrac{3}{8}\nu_{13} + 2\nu_{20}) \\
V^{(15)} &= u^2\,(3\nu_{15}^2 + 2\nu_{15} - 3\nu_{14} + \nu_{21})
\end{aligned} \tag{17}$$

$$\begin{aligned}
R^{(1)} &= (1 - u^2 - \tfrac{1}{2} e^2)\,(- 2\nu_1 - \tfrac{3}{2}\nu_4 + \tfrac{1}{2}\nu_5) \\
&\quad + e'^2\,(\tfrac{5}{4}\nu_1 + \tfrac{3}{4}\nu_4 + \tfrac{3}{2}\nu_5^2 - \tfrac{5}{4}\nu_5 + \tfrac{3}{8}\nu_{12} + \tfrac{9}{8}\nu_{13}) \\
R^{(2)} &= ee'\,(- \tfrac{9}{2}\nu_2 - 3\nu_3^2 + \tfrac{3}{2}\nu_3 + \tfrac{3}{2}\nu_8 - \tfrac{9}{2}\nu_{11}) \\
R^{(3)} &= e\,(\nu_2 + 4\nu_3 - 3\nu_{11}) \\
R^{(4)} &= e'\,(\tfrac{3}{2}\nu_1^2 + \tfrac{1}{4}\nu_1 + \tfrac{3}{4}\nu_4 + \tfrac{3}{4}\nu_5 + \tfrac{1}{4}\nu_{12}) \\
R^{(5)} &= e'\,(- \tfrac{3}{2}\nu_1^2 - \tfrac{3}{4}\nu_1 - \tfrac{9}{4}\nu_4 - \tfrac{9}{4}\nu_5 + \tfrac{3}{4}\nu_{13}) \\
R^{(9)} &= e^2\,(- \tfrac{27}{16}\nu_6 + \tfrac{27}{4}\nu^9 - \tfrac{81}{16}\nu_{16}) \\
R^{(10)} &= e^2\,(\tfrac{3}{16}\nu_7 - \tfrac{1}{4}\nu_{10} + \tfrac{1}{16}\nu_{17}) \\
R^{(11)} &= ee'\,(\tfrac{3}{2}\nu_2 + 3\nu_3^2 - \tfrac{1}{2}\nu_3 + \tfrac{3}{2}\nu_{11} + \tfrac{1}{2}\nu_{18}) \\
R^{(12)} &= e'^2\,(\tfrac{9}{4}\nu_1^2 + \tfrac{3}{8}\nu_1 + \tfrac{27}{16}\nu_4 + \tfrac{17}{16}\nu_5 - \tfrac{3}{8}\nu_{12} + \tfrac{1}{8}\nu_{19}) \\
R^{(13)} &= e'^2\,(- \tfrac{9}{4}\nu_1^2 - \tfrac{9}{8}\nu_1 - \tfrac{51}{16}\nu_4 - \tfrac{3}{2}\nu_5^2 - \tfrac{7}{16}\nu_5 - \tfrac{21}{8}\nu_{13} + \nu_{20}) \\
R^{(15)} &= u^2\,(\tfrac{3}{2}\nu^{14} - 2\nu_{15} + \tfrac{1}{2}\nu_{21})
\end{aligned} \tag{18}$$

$$
\begin{aligned}
B^{(a)} &= u\ (-\ \nu_1 - \nu_{15}) \\
B^{(b)} &= ue'\ (-\ \nu_1 - \tfrac{3}{2}\nu_4 + \nu_{15} - \tfrac{1}{2}\nu_{21}) \\
B^{(c)} &= ue'\ (-\ \nu_1 + \tfrac{1}{2}\nu_5 - \tfrac{3}{2}\nu_{14} + \nu_{15}) \\
B^{(d)} &= ue\ (\ 2\nu_3 - 2\nu_{22})
\end{aligned}
\tag{19}
$$

The values of $N^{(i)}$ are as follows:

$$
\begin{array}{llll}
N^{(1)} = & \lambda' - \lambda & N^{(2)} = & 2\lambda' - 2\lambda - \omega' + \omega \\
N^{(3)} = & -\lambda' + 2\lambda - \omega & N^{(4)} = & \lambda - \omega' \\
N^{(5)} = & 2\lambda' - \lambda \quad - \omega' & N^{(6)} = & -2\lambda' + 3\lambda + \omega' \quad - 2\omega \\
N^{(7)} = & \lambda + \omega' \quad - 2\omega & N^{(8)} = & 3\lambda' - 2\lambda - 2\omega' + \omega \\
N^{(9)} = & -\lambda' + 3\lambda - 2\omega & N^{(10)} = & \lambda' + \lambda \quad - 2\omega \\
N^{(11)} = & 2\lambda - \omega \quad - \omega' & N^{(12)} = & \lambda' + \lambda \quad - 2\omega' \\
N^{(13)} = & 3\lambda' - \lambda \quad - 2\omega' & N^{(14)} = & \lambda + \omega' \\
N^{(15)} = & \lambda' + \lambda & N^{(16)} = & 3\lambda - \omega' \quad - 2\omega \\
N^{(17)} = & 2\lambda' + \lambda \quad - \omega' - 2\omega & N^{(18)} = & \lambda' + 2\lambda - 2\omega' - \omega \\
N^{(19)} = & 2\lambda' + \lambda \quad - 3\omega' & N^{(20)} = & 4\lambda' - \lambda \quad - 3\omega' \\
N^{(21)} = & 2\lambda' + \lambda \quad - \omega' & N^{(a)} = & \lambda \\
N^{(b)} = & \lambda' + \lambda \quad - \omega' & N^{(c)} = & \lambda' - \lambda \quad - \omega' \\
 & & N^{(d)} = & 2\lambda - \omega
\end{array}
\tag{20}
$$

From these values of N the corresponding values of ν are derived, remembering that

$$\nu = \frac{n'}{i'n' + in}$$

i' and i being the coefficients of λ' and λ respectively in the value of N.

The check on the correctness of the preceding values of V, R, and B may now be applied by developing ν in powers of $\frac{n'}{n}$, and retaining only the first term; that is, by putting $\nu = \frac{1}{i}$, $\nu^2 = 0$. Making these substitutions, all the values of V, R, and B will be found to vanish. In other words, μ^2 will be the lowest power of μ which will enter into the values of V, R, or B, as we have already shown from *a priori* considerations.

For convenience, we shall give the values of V, R, and B developed according to the powers of μ, the ratio of the mean motions, a form similar to that in which the lunar inequalities are developed in the theory of the moon. Putting

$$\frac{i'}{i} = s,$$

we have

$$\nu = \frac{\mu}{i}\{1 - s\mu + s^2\mu^2 - s^3\mu^3 + \text{etc.}\}$$

$$\nu^2 = \frac{\mu^2}{i^2}\{1 - 2s\mu + 3s^2\mu^2 - 4s^3\mu^3 + \text{etc.}\}$$

We shall also put

$$V_1 = \frac{V}{\alpha^3} = \frac{cV}{\mu^2}$$
$$R_1 = \frac{R}{\alpha^3} = \frac{cR}{\mu^2},$$
$$B_1 = \frac{B}{\alpha^3} = \frac{cB}{\mu^2};$$

c being a constant, equal to unity if we neglect the change of mean distance produced by the action of other planets. We then have

$$\begin{aligned}
\delta v \quad &= mac\Sigma V_1 \sin N, \\
\delta \log r &= mac\Sigma R_1 \cos N, \\
\delta\beta \quad &= mac\Sigma B_1 \sin N.
\end{aligned} \tag{21}$$

Substituting the above developments for the ν's in V, R, and B, we have

$$\begin{aligned}
V_1^{(1)} &= (1 - u^2 - \tfrac{1}{2} e^2)(-1 - \mu^2 - 6\mu^3 - 19\mu^4) \\
&\qquad + e'^2(1 - 2\mu^2 - 30\mu^3) \\
V_1^{(2)} &= ee'(-\tfrac{3}{4} - \tfrac{3}{8}\mu^2 - \tfrac{27}{16}\mu^3) \\
V_1^{(3)} &= e(\tfrac{1}{2} + \tfrac{1}{8}\mu^2 + \tfrac{3}{8}\mu^3 + \tfrac{19}{32}\mu^4) \\
V_1^{(4)} &= e'(-\tfrac{1}{2} + \mu^2 + 9\mu^3 + 25\mu^4) \\
V_1^{(5)} &= e'(-\tfrac{3}{2} - 3\mu^2 - 27\mu^3 - 135\mu^4) \\
V_1^{(9)} &= e^2(\tfrac{3}{8} + \tfrac{1}{24}\mu^2 + \tfrac{1}{12}\mu^3) \\
V_1^{(10)} &= e^2(-\tfrac{1}{8} - \tfrac{1}{8}\mu^2 + \tfrac{3}{4}\mu^3) \\
V_1^{(11)} &= ee'(-\tfrac{1}{4} + \tfrac{1}{8}\mu^2 + \tfrac{9}{16}\mu^3) \\
V_1^{(12)} &= e'^2(-\tfrac{1}{8} - 2\mu^2 - \tfrac{9}{4}\mu^3) \\
V_1^{(13)} &= e'^2(-\tfrac{17}{8} - \tfrac{23}{8}\mu^2 - \tfrac{255}{4}\mu^3)
\end{aligned} \tag{22}$$

$$\begin{aligned}
R_1^{(1)} &= (1 - u^2 - \tfrac{1}{2} e^2)(1 - 2\mu^2 - 6\mu^3 - 14\mu^4 - 30\mu^5) \\
&\qquad + e'^2(-1 - 4\mu^2 - 24\mu^3) \\
R_1^{(2)} &= ee'(\tfrac{3}{4} - \tfrac{3}{4}\mu^2 - \tfrac{15}{8}\mu^3) \\
R_1^{(3)} &= e(\tfrac{1}{2} - \tfrac{1}{4}\mu^2 - \tfrac{3}{8}\mu^3 - \tfrac{7}{16}\mu^4) \\
R_1^{(4)} &= e'(-\tfrac{1}{2} - 2\mu^2 - 6\mu^3 - 17\mu^4) \\
R_1^{(5)} &= e'(\tfrac{3}{2} - 6\mu^2 - 30\mu^3 - 116\mu^4) \\
R_1^{(9)} &= e^2(\tfrac{3}{8} - \tfrac{1}{12}\mu^2 - \tfrac{1}{12}\mu^3) \\
R_1^{(10)} &= e^2(\tfrac{1}{8} - \tfrac{1}{4}\mu^2 + \tfrac{3}{4}\mu^3) \\
R_1^{(11)} &= ee'(-\tfrac{1}{4} - \tfrac{1}{4}\mu^2 - \tfrac{3}{8}\mu^3) \\
R_1^{(12)} &= e'^2(-\tfrac{1}{8} - \tfrac{1}{2}\mu^2 + \tfrac{9}{4}\mu^3) \\
R_1^{(13)} &= e'^2(\tfrac{17}{8} - \tfrac{31}{2}\mu^2 - \tfrac{405}{4}\mu^3) \\
R_1^{(15)} &= u^2(1 - 2\mu^2 + 14\mu^3)
\end{aligned} \tag{23}$$

$$\begin{aligned}
B_1^{(a)} &= u(2 + 2\mu^2 + 2\mu^4) \\
B_1^{(b)} &= e'u(1 + 4\mu^2 - 6\mu^3) \\
B_1^{(c)} &= e'u(1 + 4\mu^2 - 6\mu^3) \\
B_1^{(d)} &= eu(1 + \tfrac{1}{4}\mu^2 + \tfrac{1}{16}\mu^4)
\end{aligned} \tag{24}$$

Such are the formulæ by which we shall proceed to compute the perturbations of Neptune by Jupiter, Saturn, and Uranus.

It will be noticed that the coefficient of μ vanishes identically in the last developments. I have not completely investigated this law, but it seems to arise from the circumstance that that portion of the perturbation in question which proceeds from the change in the origin of co-ordinates is independent of μ, while that portion which is caused by the modified attraction of the Sun is of the order of magnitude μ^2. It furnishes a yet more valuable check than the last on the developments.

§ 11. Allusion has already been made to the complications introduced into the theory of Neptune by the near approach of its mean motion to double that of Uranus, and the consequent oscillation of all the elements of its orbit in a cycle of 4300 years of duration. In order to construct a dynamical theory which should be correct within a tenth of a second through the whole of one of these cycles, it would be necessary to include many terms dependent on the second, and perhaps some dependent on the third power of the masses of the disturbing planets.

If this task were accomplished, the necessary uncertainty in the mass of Uranus and the elements of Neptune would destroy all the value of the theory. A change of one-tenth in the mass of Uranus would produce a change of 200″ in the coefficient of the perturbation of the mean longitude. The mean motions of Walker and Kowalski being each about 8″ in error, the place of the planet from this cause alone would be in error by nearly 10° at the end of a cycle.

After much careful consideration of different ways of relieving the theories of Uranus and Neptune from the complexities introduced by the large perturbations referred to, I finally determined to develop them not as perturbations of the co-ordinates, but of the elements. It will readily be seen that if the eccentricity or perihelion is greater than the mean during several revolutions of the planet, there will be a perturbation in the radius vector and longitude having nearly the same period with the revolution of the planet, although the latter may really scarcely wander from a true elliptic orbit during an entire revolution. In such a case it is clearly best, in constructing a theory designed to remain of the highest degree of exactness for only a few centuries, to take not the mean values of the elements, but their values at a particular epoch during the time the theory is expected to be used.

In doing this, we shall be treating the change in the elements in the same way that the secular variations are usually treated. These variations are really periodic, and in a perfect theory would have to be treated as such. But the elliptic elements on which all our planetary theories are founded are not mean elements, but elements brought up by secular variation to the epoch 1800 or 1850.

Thus, our perturbations of the elements will be of the form

$$\delta a = c + a_1 t + \Sigma a_2 \begin{smallmatrix}\sin\\ \cos\end{smallmatrix} \{ kt + \varepsilon \},$$

in which a' is the secular variation proper, k a small coefficient equal to $2n' - n$ or its multiples, and c a constant added to the integral, of such value as to make δa vanish at the epoch 1850.

§ 12. *Adopted elements and masses.*

The elements of Neptune adopted in the computation of the perturbations are obtained by correcting those of Walker so as to agree with the Lalande observations, and as nearly as possible with seven normal places derived from the modern observations from 1846 to 1863. The latter series is thus represented within a second of arc. As these elements are merely provisional, it is not worth while to give any details of the corrections, except their amounts, which are as follows:

$$\begin{array}{llrl}
\delta\pi = -4^\circ\,11'\,18''.6; & \pi & = & 43^\circ\,3'\,18''.6 \\
\delta e = -.00025451; & e & = & .00846495 \\
\delta n = -8''.406; & n & = & 7864''.368 \\
\delta\varepsilon = -3'\,5''.92; & \varepsilon & = & 335\ 5\ 31.10 \\
& \log a & = & 1.4780405 \\
& i & & 1^\circ\,47'\,1'' \\
& \Omega & & 130\quad 7\ 20
\end{array}$$

Epoch, Jan. 0, 1850, Greenwich, M. noon.

To obtain the value of log a, the mean motion was diminished by the secular variation of the longitude of the epoch $= 21''.354$. A more exact value of this quantity will appear, in the course of our computations, to be $21''.4426$.

The provisional inclination and longitude have been taken from Walker without change, as the small corrections which his values of these elements may require will not affect the perturbations.

The adopted elements of Uranus, Saturn, and Jupiter, with their functions used in the theory for the same epoch, are as follows:

	Uranus.	Saturn.	Jupiter.
π	167° 34′ 21″	90° 4′ 0″	11° 54′ 51″
ε	28 27 14	14 48 40	159 56 20
i	0 46 30	2 29 28.8	1 18 41.1
θ	73 14 14	112 22 14	98 56 10
n	15425.030	43996.127	109256.72
e —	.0466972	.0560050	.0482273
$\log a$	1.2837047	0.9802225	0.7162201
τ	335°38′	77°56′	355°52′
u	.0131517	.0083880	.0082735
α	0.638195	0.317301	0.1727703
m	$\frac{1}{21000}$	$\frac{1}{3501.6}$	$\frac{1}{1047.879}$

These elements of Uranus have been obtained by applying to Peirce's values of the mean elements (Appendix to American Ephemeris and Nautical Almanac, 1860–64, p. 4) approximate long-period perturbations of the elements produced by Neptune at the epoch 1850. The elements of Jupiter and Saturn are from Hansen's prize memoir on the mutual perturbations of those planets, and are, substantially, the same as Bouvard's.

The values of those constants which depend on the ratio of the mean distances are as follows, using the notation of the Mécanique Céleste:

I.—URANUS AND NEPTUNE.

i	$b_{\frac{1}{2}}^{(i)}$	$a\dfrac{db_{\frac{1}{2}}^{(i)}}{da}$	$a^2\dfrac{d^2b_{\frac{1}{2}}^{(i)}}{da^2}$	$a^3\dfrac{d^3b_{\frac{1}{2}}^{(i)}}{da^2}$	$a^4\dfrac{d^4b_{\frac{1}{2}}^{(i)}}{da^2}$
0	2.26969	0.72903	1.8326	6.4384	35.17
1	—1.68379	6.05279	—13.0023	65.5556	—259.42
2	0.37751	0.95867	2.1283	6.7135	35.99
3	0.20310	0.72530	2.2389	7.4924	36.95
4	0.11422	0.52446	2.1024	8.2270	39.52
5	0.06593	0.36954	1.8319	8.5192	43.00
6	0.03870	0.25606	1.5157	8.302	46.01
7	0.02299	0.17533	1.2085	7.679	47.57
8	0.01379	0.11900	0.9365	6.804	47.27
9	0.00832	0.0802	0.7100	5.818	45.18
10	0.0051	0.054	0.533		

i	$ab_{\frac{3}{2}}^{(i)}$	$a^2\dfrac{db_{\frac{3}{2}}^{(i)}}{da}$	$a^3\dfrac{d^2b_{\frac{3}{2}}^{(i)}}{da^2}$
0	—0.8966	26.5493	2.80
1	3.2907	11.9366	60.92
2	2.4710	11.0760	59.76
3	1.7806	9.6115	57.07
4	1.2524	7.9427	52.59
5	0.8668	6.3301	46.80
6	0.5931	4.9065	40.34
7	0.4023	3.7215	33.83
8	0.2711	2.7738	27.69
9	0.1817	2.0381	22.20

It will be observed that in $b_{\frac{1}{2}}^{(1)}$, $ab_{\frac{3}{2}}^{(0)}$, and their differential coefficients, we have included those multiples of $\frac{1}{\alpha^2}$ which are introduced by the action of Uranus on the Sun. It seemed less laborious to do this than to make a separate computation of the terms produced by this cause. But for Saturn and Jupiter $\frac{1}{\alpha^2}$ is so large that it will be better to use the developments previously given.

II.—SATURN AND NEPTUNE.

i	$b_{\frac{1}{2}}^{(i)}$	$a\frac{db_{\frac{1}{2}}^{(i)}}{da}$	$a^2\frac{d^2b_{\frac{1}{2}}^{(i)}}{da^2}$	$a^3\frac{d^3b_{\frac{1}{2}}^{(i)}}{da^3}$
0	2.05341	0.11342	0.14186	0.0986
1	0.33010	.35745	.08964	.1313
2	.07890	.16509	.19632	.1075
3	.02091	.06476	.14027	.1878
4	.00581	.02383	.07517	.1701
5	.00166	.00847	.03514	

i	$ab_{\frac{3}{2}}^{(i)}$	$a^2\frac{db_{\frac{3}{2}}^{(i)}}{da}$
0	0.8045	0.4003
1	0.3686	.5242
2	.1443	.3456
3	.0531	.1794
4	.0189	
5	0066	

III.—JUPITER AND NEPTUNE.

i	$b_{\frac{1}{2}}^{(i)}$	$a\frac{db_{\frac{1}{2}}^{(i)}}{da}$	$a^2\frac{d^2b_{\frac{1}{2}}^{(i)}}{da^2}$	$a^3\frac{d^3b_{\frac{1}{2}}^{(i)}}{da^3}$
0	2.01518	0.03088	0.0330	0.0067
1	0.17474	.17876	.0124	.0139
2	.02267	.04592	.0483	.0074
3	.00327	.00989	.0202	.0221
4	.00049	.00199	.0061	.0125

	$ab_{\frac{3}{2}}^{(i)}$	$a^2\frac{db_{\frac{3}{2}}^{(i)}}{da}$
0	0.3699	0.4209
1	.0948	.2005
2	.0204	.0634
3	.0041	.0168
4	0.0008	

§ 13. From these data the coefficients h of the different terms of the perturbative function, their differential coefficients, and the perturbations of the coordinates, are found to be as in the following table. The N's, it will be seen, are grouped according to the values of their constant parts, $j'\omega' + j\omega$.

h, its differential coefficients, L, W, and E, are given in units of the *third place* of decimals, to avoid writing zeros. The logarithms are reduced to the common base, 10, and are expressed in units of the seventh place.

ACTION OF URANUS.

I.—$j=0$; $j'=0$; $\iota=0$.

i'	0	+1	2	3	4	5	6	7	8	9
i	0	−1	−2	−3	−4	−5	−6	−7	−8	−9
h	+1135.50	−840.31	+187.98	+100.37	+55.83	+31.75	+18.29	+10.63	+6.2	+3.7
$aDah$	+367.47	+3025.10	+478.7	+359.3	+256.9	+178.5	+121.4	+81.2	+53.6	+36
$De'h$	+6.96	+12.52	−4.1	−7.6	−8.7	−8.4	−7.4	−6.2	−5.0	−4
$\frac{1}{4}Duh$	−10.84	−2.56	−8.35	−6.1	−4.3	−3.0	−2.1	−1.4	−1.0	
L	+3005.97	+1747.45	+1919.99	+1232.4	+799.6	+519.5	+336.3	+216.9	+138.9	+91
$e'W$	6.96	+12.52	−4.1	−7.6	−8.7	−8.4	−7.4	−6.2	−5.0	
E	0	+3.56	−1.6	−1.3	−0.9	−0.7	−0.5	−0.3	−0.2	
		″	″	″	″	″	″	″	″	″
$\delta l \div \sin N$		−17.853	−9.808	−4.197	−2.043	−1.061	−0.572	−0.317	−0.178	−0.102
$\delta v \div \sin(N-f)$		+0.013	−0.112	−0.066	−0.042	−0.028	−0.018	−0.012	−0.008	
$N+f$		−0.060	−0.096	−0.057	−0.037	−0.025	−0.017	−0.011	−0.008	
$N-2f$		+0.000	−0.001	−0.001						
$N+2f$		−0.001	−0.001	−0.001						
$\delta \log r \div \cos N$		+361	−81	−43	−24	−14	−8	−5	−3	−2
$N-f$		0	−1	−1	0	0	0	0	0	0
$N+f$		0	+1	+1	0	0	0	0	0	0
		″	″	″	″	″	″	″	″	
$\delta\beta \div \sin(N-V)$		−0.030	+0.055	+0.028	+0.014	+0.008	+0.005	+0.003	+0.002	
$(N+V)$		+0.083	+0.030	+0.014	+0.007	+0.004	+0.002	+0.001	+0.001	

II.—$j=1$; $j'=-1$; $\iota=0$.

i'	−7	−6	−5	−4	−3	−2	−1	0	+1	2	3	4	5	6	7
i	+7	6	5	4	3	2	1	0	−1	−2	−3	−4	−5	−6	−7
h	+0.21	+0.26	+0.30	+0.33	+0.32	+0.24	+0.05	−0.24	−0.32	−0.91	+0.35	+0.48	+0.50	+0.46	+0.40
$aDah$	+1.8	+1.9	+1.9	+1.65	+1.16	+0.38	−0.56	−1.32	−1.50	+1.05	+0.20	+1.24	+2.00	+2.37	+2.5
$De'h$	+24.8	+30.5	+35.1	+38.5	+37.4	+27.93	+5.69	−28.77	−38.29	−107.13	+40.77	+56.1	+58.0	+53.0	+44.5
L	+4.8	+5.2	+5.4	+5.1	+4.1	+2.10	−0.82	−2.24	−4.80	−3.01	+2.4	+5.1	+6.8	+7.3	+7.2
$e'W$	+24.8	+30.5	+35.1	+38.5	+37.4	+27.93	+5.69	−28.77	−38.29	−107.13	+40.77	+56.1	+58.0	+53.0	+44.5
E	+24.6	+30.3	+34.9	+38.3	+37.2	+27.81	+5.55	−28.95	−38.47	−107.20	+40.61	+55.9	+57.6	+52.4	+43.7
	″	″	″	″	″	″	″		″	″	″	″	″	″	″
$\delta l \div \sin N$	+0.007	+0.009	+0.011	+0.013	+0.014	+0.011	−0.008		+0.049	+0.015	−0.008	−0.013	−0.014	−0.012	−0.010
	″	″	″												
$\delta v \div \sin(N-f)$	−0.072	−0.103	−0.143	−0.196	−0.255	−0.284	−0.115		−0.783	−1.095	+0.277	+0.286	+0.236	+0.179	+0.130
$N-2f$	−0.001	−0.001	−0.002	−0.002	−0.003	−0.003	−0.001		−0.008	−0.012	+0.003	+0.003	+0.002	+0.002	+0.001
$N+f$							−0.002		+0.002						
$\delta \log r \div \cos N-f$	−1	−1	−1	−2	−3	−3	−1		−8	−11	+3	+3	+2	+2	+1

III.—$j=-1$; $j'=0$; $\iota=0$.

i'	−5	−4	−3	−2	−1	0	+1	2	3	4	5	6	7	8
i	+6	5	4	3	2	1	0	−1	−2	−3	−4	−5	−6	−7
h	+6.5	+9.0	+11.4	+12.7	−219.7	−17.00	−62.71	−57.573	−45.20	−33.27	−23.65	−16.41	−11.20	−7.6
$aDah$	+34.1	+36.0	+32.1	+17.4	+444.1	−59.5	−120.55	−161.57	−170.23	−157.9	−135.8	−110.3	−86.4	−66.2
$De'h$	−2.0	−1.7	−1.3	−1.0	+1.01	−1.50	−1.29	+0.61	+2.96	+4.85	+6.0	+6.4	+6.2	+5.7
$\frac{1}{4}Duh$	0	0	0	+0.5	+2.75	+2.31	+3.23	+3.61	+3.48	+3.09	+2.6	+2.2	+1.4	+1.2
L	+95.5	+108.6	+108.7	+79.8	+223.3	−153.0	−178.40	+8506.72	−871.70	−594.2	−443.5	−331.0	−244.5	−180
$e'W$	−2.0	−1.7	−1.3	−1.0	+1.01	−1.50	−1.29	+0.61	+2.96	+4.85	+6.0	+6.4	+6.2	+5.7
E	+0.1	+0.2	+0.2	+0.1	−0.95	0.00	+0.27	+0.49	+0.57	+0.56	+0.5	+0.4	+0.3	+0.3
	″	″	″	″	″	″	″		″	″		″	″	″
$\delta l \div \sin N$	+0.138	+0.184	+0.220	+0.202	+0.750	−0.766	−1.752	+2163.605	+9.279	+3.098	+1.531	+0.854	+0.504	+0.308
$\delta v \div \sin(N-f)$	+0.004	+0.004	+0.004	+0.004	+0.006	+0.001	−0.005		+0.116	+0.054	+0.035	+0.025	+0.018	+0.013
$(N+f)$	+0.004	+0.005	+0.005	+0.005	0	+0.001	0		+0.104	+0.049	+0.032	+0.022	+0.016	+0.012
$\delta \log r \div \cos N$	−2	−2	−3	−3	+31	0	−26		+61	+29	+17	+11	+6	+4
$(N-f)$									+1	+1				
$(N+f)$									−1	−1				
				″	″	″	″		″	″	″	″	″	″
$\delta\beta \div \sin(N-V)$	0	0	0	+0.002	+0.004	+0.012	+0.036		−0.016	−0.021	−0.011	−0.007	−0.004	−0.007
$\sin(N+V)$				+0.001	+0.014	+0.012	+0.028		−0.028	−0.011	−0.006	−0.004	−0.002	−0.001

IV.—$j=0$; $j'=-1$; $\iota=0$.

i'	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8	9
i	+6	5	4	3	2	1	0	−1	−2	−3	−4	−5	−6	−7	−8
h	−0.68	−0.91	−1.13	−1.21	−0.72	+32.75	+12.73	+4.267	+12.016	+9.00	+6.43	+4.47	+3.04	+2.05	+1.35
$aDah$	−4.17	−4.56	−4.29	−2.71	+0.97	−54.83	+14.12	+47.61	+33.38	+33.80	+30.55	+25.64	+20.5	+15.8	+11.8
$De'h$	−79.9	−107.5	−133.8	−142.5	−85.17	+3865.68	+1503.24	+504.23	+1418.28	+1061.5	+758.9	+527.1	+358.7	+240.1	+158.8
$\frac{1}{4}Duh$	0	0	0	−0.1	−0.16	−0.52	−0.51	−0.611	−0.72	−0.68	−0.6	−0.5	−0.4	−0.3	0
L	−11.5	−13.2	−13.5	−10.3	−0.62	−27.80	+21.87	−557.07	+214.18	+147.4	+111.0	+83.5	+62.0	+45.3	+32.1
E	−80.1	−107.5	−133.9	−142.6	−85.24	+3865.40	+1502.86	+504.02	+1418.32	+1061.7	+759.4	+527.7	+359.3	+240.7	+159.4
	″	″	″	″	″	″	″	″	″	″					
$\delta l \div \sin N$	−0.017	−0.022	−0.027	−0.026	−0.002	−0.139	+0.215	−141.69	−2.279	−0.770	−0.383	−0.216	−0.128	−0.077	−0.046
$\delta v \div \sin(N-f)$	+0.232	+0.364	+0.543	+0.721	+0.573	−38.716	−29.524		+30.174	+11.061	+5.239	+2.720	+1.478	+0.823	+0.467
$N-2f$	+0.002	+0.004	+0.006	+0.008	+0.006	−0.411	−0.313		+0.321	+0.117	+0.055	+0.029	+0.016	+0.009	+0.005
$N-3f$	0	0	0	0	0	−0.005	−0.003		+0.004	+0.001	+0.001	0	0	0	0
$N+f$	0	0	0	0	0	−0.002	−0.001		−0.011	−0.008	−0.005	−0.003	−0.002	−0.002	−0.001
$\delta \log r \div \cos N$	0	0	0	0	0	+2	+6		−17	−8	−5	−3	−2	−1	0
$\div \cos(N-f)$	+2	+4	+6	+8	+6	−408	−311		+318	+116	+55	+29	+15	+9	+6
$N-2f$	0	0	0	0	0	−5	−4		+4	+1	+1	0	0	0	0
						″	″		″	″	″	″			
$\delta\beta \div \sin(N+V)$	0	0	0	0	0	−0.003	−0.005		−0.005	−0.002	−0.001	−0.001	0	0	0
$(N-V)$	0	0	0	0	0	−0.003	−0.005		−0.010	−0.005	−0.003	−0.002	−0.001	0	0

V.—$j=-2$; $j'=1$; $\iota=0$.

i'	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8
i	5	4	3	2	1	0	−1	−2	−3	−4	−5	−6	−7
h	+0.03	+0.02	−0.07	+0.01	+0.02	+0.006	−0.0145	−0.033	−0.016	−0.055	−0.06	−0.05	−0.05
$aDah$	+0.1	+0.0	+0.2	0.0	+0.08	+0.08	+0.014	−0.11	−0.25	−0.34	−0.40	−0.44	−0.44
$2De'h$	+6.5	+4.6	−15.9	+1.4	+5.1	+1.3	−3.87	−7.9	−11.0	−13.0	−13	−12	−11
	″				″	″	″	″	″	″	″	″	″
$\delta l \div \sin N$	+0.001	0	0	0	+0.001	+0.002	+0.56	+0.007	+0.005	+0.004	+0.003	+0.002	+0.002
$\delta v \div \sin(N+f)$	−0.011	−0.009	+0.040	−0.005	−0.026	−0.013		−0.084	−0.057	−0.044	−0.032	−0.024	−0.019

VI.—$j=1$; $j'=-2$; $\iota=0$.

i'	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8
i	+5	4	3	2	1	0	−1	−2	−3	−4	−5	−6	−7
h	−.002	−.002	−.001	−.001	−.002	−.004	−.0058	−.007	+.006	+.012	+.016	+.018	+.018
$2De'h$	−1.0	−0.9	−0.7	−0.65	−1.04	−2.10	−2.80	−3.47	+2.86	+5.9	+7.8	+8.6	+8.6
							″	″					
δl	0	0	0	0	0	0	+0.21	−0.001	0	0	0	0	0
	″	″	″	″	″	″		″	″	″	″	″	″
$\delta v \div \sin(N-f)$	+0.002	+0.002	+0.002	+0.002	+0.005	+0.021		−0.037	+0.015	+0.020	+0.020	+0.017	+0.015

VII.—$j=1$; $j'=0$; $\iota=-2$.

i'	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8
i	+5	4	3	2	1	0	−1	−2	−3	−4	−5	−6	−7
h							−0.031						
$\frac{1}{4}Duh$	−1.3	−1.7	−1.9	−2.2	−2.2	−1.85	−1.17	−0.66	−0.3	−0.1	0	0	0
							″						
$\delta l \div \sin N$							+1.11						
	″	″	″	″	″	″	″	″	″				
$\delta\beta \div \sin(N-V)$	−0.004	−0.007	−0.010	−0.015	−0.022	−0.036	−0.58	+0.007	+0.002	0	0	0	0

VIII.—$j = 0$; $j' = 1$; $\iota = -2$.

i'	+4	−3	−2	−1	0	1	2	3	4	5	6	7
i	+5	4	3	2	1	0	−1	−2	−3	−4	−5	−6
$2\,De'h$	+1.6	+1.8	+1.8	+1.6	+2.3	+0.4	+0.10	−0.09	−0.18	−0.21	−0.17	−0.14
$\frac{1}{8}\,Duh$	+0.5	+0.6	+0.6	+0.5	+0.75	+0.15	+0.033	−0.03	−0.06	−0.06	−0.04	0
	″	″	″	″	″	″		″	″	″		
$\delta v \div \sin(N+f)$	−0.003	−0.004	−0.005	−0.005	−0.012	−0.004		−0.001	−0.001	−0.001	0	0
	″	″	″	″	″	″						
$\delta\beta \div \sin(N-V)$	+0.001	+0.001	+0.002	+0.002	+0.004	+0.001		0	0	0	0	0

IX.—$j = -2$; $j' = 0$; $\iota = 0$.

i'	−3	−2	−1	0	1	2	3	4	5	6	7	8	9
i	−5	4	3	2	1	0	−1	−2	−3	−4	−5	−6	−7
h	+0.66	+0.64	−17.57	+0.10	+0.214	+2.766	+3.750	+3.944	+3.660	+3.151	+2.58	+2.04	+1.57
$aDah$	+2.07	+1.36	+39.8	+1.36	+5.03	+9.55	+15.48	+19.71	+21.67	+21.6	+20.2	+18.0	+15.4
$De'h$	−0.06	−0.01	+0 19	+0.07	+0.12	+0.06	−0.17	−0.51	−0.86	−1.15	−1.35	−1.4	−1.4
L	+6.4	+4.7	+33.7	+2.9	+10.3	+16.3	+5.32	−565.6	+112.77	+80.22	+64.9	+53.1	+41.9
	″	″	″	″	″	″	″	″	″	″	″	″	″
$\delta l \div \sin N$	+0.009	+0.008	+0.068	+0.007	+0.034	+0.080	+0.050	−71.93	−1.253	−0.425	−0.227	−0.138	−0.087
$\delta v \div \sin(N-f)$	0	0	0	0	0	0	+0.002	0	−0.021	−0.010	−0.007	−0.005	−0.003
$(N+f)$	0	0	0	0	0	0	+0.001	0	−0.018	−0.009	−0.007	−0.005	−0.003

X.—$j = -1$; $j' = -1$.

i'	−3	−2	−1	0	1	2	3	4	5	6	7	8	9
i	+5	4	3	2	1	0	−1	−2	−3	−4	−5	−6	−7
h	−0.113	−0.107	−0.090	+2.814	−0.325	−1.305	−1.903	−2.067	−1.954	−1.700	−1.40	−1.12	−0.86
$aDah$	−0.50	−0.42	−0.40	−6.48	−1.50	−3.38	−6.03	−8.30	−9.63	−10.01	−9.62	−8.74	−7.58
$De'h$	−13.3	−12.5	−10.5	+331.8	−38.3	−154.2	−224.67	−243.19	−228.57	−197.7	−161.6	−127.3	−96.9
L	−1.4	−1.2	−1.1	−5.9	−3.5	−6.11	−0.38	+29.95	−57.29	−40.85	−33.2	−27.4	−22.3
E	−13.3	−12.5	−10.5	+331.8	−38.7	−154.2	−224.65	−243.20	−228.68	−197.8	−161.8	−127.5	−97.0
	″	″	″	″	″	″	″	″	″	″	″	″	″
$\delta l \div \sin N$	−0.002	−0.002	−0.002	−0.015	−0.011	−0.030	−0.003	+38.09	+0.636	+0.217	+0.116	+0.065	+0.042
$\delta v \div \sin(N-f)$	+0.038	+0.042	+0.042	−1.662	+0.257	+1.514	+4.250		−5.074	−2.102	−1.131	−0.664	−0.402
$(N-2f)$	0	0	0	−0.017	+0.003	+0.016	+0.045		−0.054	−0.022	−0.012	−0.007	−0.004
$\delta \log r \div \cos N$	0	0	0	0	0	0	−2		+5	+2	+1	+1	0
$(N-f)$	0	0	0	−17	+3	+16	+44		−53	−22	−12	−7	−4

XI.—$j = 0$; $j' = -2$.

i'	−3	−2	−1	0	1	2	3	4	5	6	7	8	9
i	+5	4	3	2	1	0	−1	−2	−3	−4	−5	−6	−7
h	0	0	0	+.01	+0.01	+0.14	+0.169	+0.2677	+0.259	+0.228	+0.206	+0.152	+0.118
$aDah$	+.03	+.03	+.03	+0.06	+0.18	+0.25	+0.655	+0.810	+1.018	+1.12	+1.11	+1.04	+0.92
$De'h$	+1.1	+1.1	+1.1	+2.08	+1.76	+32.51	+40.15	+63.13	+60 52	+52.90	+42.98	+34.1	+25.8
L					+0.4	+0.50	+0.36	−39.2	+7.24	+5.15	+4.4	+3.5	+2.2
E	+1.1	+1.1	+1.1	+2.1	+1.8	+32.50	+40.15	+63.13	+60.54	+52.92	+43.01	+34.1	+25.8
					″	″	″	″	″	″	″	″	″
$\delta l \div \sin N$	0	0	0	0	+0.001	+0.002	+0.003	−4 99	−0.080	−0.027	−0.015	−0.009	−0.005
	″	″	″	″	″	″	″		″	″	″	″	″
$\delta v \div \sin(N-f)$	−0.003	−0.004	−0.004	−0.010	−0.012	−0.319	−0.757		+1.344	+0.564	+0.301	+0.178	+0.110
$(N-2f)$	0	0	0	0	0	−0.003	−0.008		+0.014	+0.006	+0.003	+0.002	+0.001
$\delta \log r \div \cos(N-f)$	0	0	0	0	0	−3	−8		+15	+6	+4	+2	+1

XII.—$j = -3$; $j' = 0$.

i'	6
i	−3
L	+ 51.5
	″
$\delta l \div \sin N$	+ 4.37

XIII.—$j = -2$; $j' = -1$.

i'	0	1	2	3	4	5	6	7	8	9	10
i	+3	2	1	0	−1	−2	−3	−4	−5	−6	−7
L							− 38.5				
$2 De'h$	+ 54.5	+ 1.4	+ 6.0	+ 23.4	+ 41.7	+ 55.17		+ 62.63	+ 58.87	+ 53.4	+ 44.8
$\delta l \div \sin N$							− 3.26				
	″	″	″	″	″	″		″	″	″	″
$\delta v \div \sin (N - f)$	− 0.091	− 0.003	− 0.015	− 0.076	− 0.201	− 0.503		+ 0.727	+ 0.320	+ 0.189	+ 0.116
$N - 2f$				− 0.001	− 0.002	− 0.005		+ 0.008	+ 0.003	+ 0.002	+ 0.001

XIV.—$j = -1$; $j' = -2$.

i'	0	1	2	3	4	5	6	7	8	9	10
i	+3	2	1	0	−1	−2	−3	−4	−5	−6	−7
L							+ 10.0				
$2 De'h$	− 0.3	− 1.8	− 2.8	− 10.9	− 20.7	− 28.4		− 33.30	− 31.7	− 28.5	− 24.6
							″				
$\div \sin N$							+ 0.85				
		″	″	″	″	″		″	″	″	″
$\delta v \div \sin (N - f)$	0	+ 0.004	+ 0.007	+ 0.036	+ 0.100	+ 0.259		+ 0.387	+ 0.172	+ 0.101	− 0.065

XV.—$j = 0$; $j' = -3$.

i'	0	1	2	3	4	5	6	7	8	9	10
i	+3	2	1	0	−1	−2	−3	−4	−5	−6	−7
$2 De'h$	0	+ 0.1	+ 0.3	+ 1.2	+ 2.3	+ 3.6	+ 4.25	+ 4.47	+ 4.24	+ 3.8	+ 3.3
			″	″	″	″		″	″	″	″
$\delta v \div \sin (N - f)$	0	0	− 0.001	− 0.004	− 0.011	− 0.033		+ 0.052	+ 0.023	+ 0.013	+ 0.009

ACTION OF SATURN.

I.—$j=0$; $j'=0$.

i'	0	1	2	3	4
i	0	−1	−2	−3	−4
h	+1026.84	+164.82	+39.15	+10.3	+2.8
$aDah$	+57.04	+178.60	+82.47	+32.3	+11.9
$De'h$	+0.780	−1.092	−1.56	−1.02	−0.5
$\frac{1}{4}Duh$	−0.773	−0.99	−0.44	−0.17	−0.06
L	+2167.76	+794.46	+268.80	+91.9	+31.2
E	0	−0.70	−0.33	−0.1	−0.1
		″	″	″	″
$\delta l \div \sin N$		−10.186	−1.723	−0.394	−0.100
$\delta v \div \sin (N-f)$		−0.109	−0.027	−0.008	−0.003
$(N+f)$		−0.091	−0.022	−0.007	−0.003
$\delta \log r \div \cos N$		−89	−21	−6	−2
		″	″		
$\delta\beta \div \sin (N+V)$		+0.004	+0.001	″	
$N-V$		+0.022	+0.005	+0.001	

II.—$j=1$; $j'=-1$.

i'	−3	−2	−1	0	1	2	3
i	+3	2	1	0	−1	−2	−3
h	+0.02	+0.04	+0.05	−0.0171	−0.044	+0.139	+0.124
$aDah$	+0.09	+0.13	+0.09	−0.058	−0.11	+0.12	+0.25
$De'h$	+2.8	+5.0	+5.89	−2.020	−5.17	+16.5	+14.7
L	+0.24	+0.39	+0.33	−0.159	−0.36	+0.68	+0.89
	″	″	″		″	″	″
$\delta l \div \sin N$	+0.001	+0.002	+0.004		+0.005	−0.004	−0.004
	″						
$\delta v \div \sin (N-f)$	−0.024	−0.064	−0.151		−0.133	+0.211	+0.124
$N-2f$	0	−0.001	−0.002		−0.001	+0.002	+0.001
$\delta \log r \div \cos (N-f)$	0	−1	−2		+1	0	0

III—$j=-1$; $j'=0$.

i'	−2	−1	0	1	2	3	4
i	+3	2	1	0	−1	−2	−3
h	+4.23	+8.48	−3.175	−28.49	−13.47	−5.32	−1.96
$aDah$	+8.4	+7.5	−7.14	−32.54	−28.59	−16.5	−8.1
$De'h$	−0.2	−0.1	−0.11	+0.15	+0.52	+0.5	+0.4
L	+27.0	+34.5	−20.63	−36.65	−106.60	−49.4	−21.9
E	0	0	0	+0.12	+0.11	+0.1	0
	″	″	″	″	″	″	″
$\delta l \div \sin N$	+0.108	+0.200	−0.217	−2.158	+1.747	+0.355	+0.101
$\delta v \div \sin (N-f)$	+0.002	+0.002	−0.001	−0.034	+0.025	+0.007	+0.003
$(N+f)$	+0.002	+0.002	−0.001	−0.020	+0.022	+0.006	+0.003
$\delta \log r \div \cos N$	−1	−2	0	−71	+18	+5	+1

IV.—$j = 0$; $j' = -1$.

i'	-3	-2	-1	0	1	2		4	5
i	$+4$	3	2	1	0	-1	—	-3	-4
h	-0.07	-0.17	-0.30	$+0.116$	$+9.171$	$+5.704$	$+2.37$	$+0.89$	$+0.32$
$aDah$		-0.50	-0.57	$+0.38$	$+1.560$	$+6.43$	$+5.02$	$+2.8$	
$De'h$	-8.1	-19.5	-35.5	$+13.8$	$+1083.89$	$+673.05$	$+277.7$	$+103.6$	$+36.7$
L		-1.5	-1.9	$+1.1$	-1.46	$+36.64$	$+18.6$	$+8.6$	
E	-8.1	-19.5	-35.5	$+13.8$	$+1083.86$	$+673.10$	$+277.8$	$+103.6$	$+36.7$
		″	″	″	″	″	″	″	
$\delta l \div \sin N$		-0.006	-0.011	$+0.012$	-0.086	-0.600	-0.134	-0.040	
	″								
$\delta v \div \sin (N - f)$	$+0.049$	$+0.156$	$+0.410$	-0.291	(-127.63)	$+22.056$	$+3.995$	$+0.955$	$+0.249$
$N - 2f$	$+0.001$	$+0.002$	$+0.004$	-0.003	-1.348	$+0.233$	$+0.042$	$+0.010$	$+0.003$
$N - 3f$	0	0	0	0	-0.015	$+0.003$			
$\delta \log r \div \cos N$	0	0	0	0	$+29$	-9	-2	-1	0
$(N - f)$	$+1$	$+2$	$+4$	-3	-1344	$+232$	$+42$	$+10$	$+3$
$(N - 2f)$	0	0	0	0	-17	$+3$	$+1$		

V.—$j = -2$; $j' = 1$.

i'	-2	-1	0	1	2	3
i	$+3$	2	1	0	-1	-2
$De'h$	$+0.7$	-0.04	$+0.07$	-0.26	-0.44	-0.39
	″	″	″	″	″	″
$\delta v \div \sin (N - f)$	-0.006	0.000	-0.002	$+0.031$	-0.014	-0.006

VI.—$j = 1$; $j' = -2$.

i'	-2	-1	0	1	2	3
i	$+3$	2	1	0	-1	-2
$De'h$				-0.11	-0.14	$+0.46$
	″	″	″	″	″	″
$\delta v \div \sin (N - f)$	0.000	0.000	0.000	$+0.013$	-0.005	$+0.007$

VII.—$j = -2$; $j' = 0$.

i'	-1	0	1	2	3	4	5
i	$+3$	2	1	0	-1	-2	-3
h	$+0.3$	-0.03	$+0.18$	$+0.66$	$+0.48$	$+0.27$	
$aDah$	$+0.4$	-0.05	$+0.34$	$+1.44$	$+1.51$	$+1.08$	
L	$+1.5$	-0.2	$+0.95$	$+2.22$	$+5.7$	$+3.2$	
	″	″	″	″	″	″	
$\delta l \div \sin N$	$+0.006$	-0.001	$+0.008$	$+0.065$	-0.129	-0.026	

VIII.—$j = -1$; $j' = 1$.

i'	-1	0	1	2	3	4	5
i	$+3$	2	1	0	-1	-2	-3
h	-0.02	0.0	-0.04	-0.50	-0.41	-0.23	-0.11
$aDah$	-0.04	-0.02	-0.11	-0.61	-0.88	-0.72	-0.45
$De'h$	-2.1	-0.49	-5.17	-59.02	-47.95	-26.96	-12.92
L	-0.1	0.0	-0.30	-0.96	-4.20	-2.41	-1.40
			″	″	″	″	″
$\delta l \div \sin N$	0	0	-0.003	-0.028	$+0.095$	$+0.020$	$+0.007$
	″	″					
$\delta v \div \sin (N - f)$	$+0.016$	$+0.005$	$+0.092$	$+3.477$	-2.178	-0.442	-0.129
$N - 2f$	0	0	$+0.001$	$+0.037$	-0.023	-0.005	-0.001
$\delta \log r \div \cos (N - f)$	0	0	$+1$	$+37$	-23	-5	-1

IX.—$j = 0$; $j' = -2$.

i'	-1	0	1	2	3	4	5
i	$+3$	2	1	0	-1	-2	-3
h	0	0	$+0.004$	$+0.081$	$+0.083$	$+0.05$	$+0.02$
$aDah$	0	0	$+0.008$	$+0.022$	$+0.098$	$+0.11$	$+0.08$
$De'h$	$+0.08$	$+0.05$	$+1.00$	$+19.12$	$+19.63$	$+11.64$	$+5.71$
L	0	0	$+0.02$	$+0.05$	$+0.72$	$+0.45$	$+0.24$
				″	″	″	″
$\delta l \div \sin (N - f)$	0	0	0	$+0.001$	-0.016	-0.004	-0.001
	″	″	″				
$\delta v \div \sin (N - f)$	-0.001	-0.001	-0.018	-1.126	$+0.891$	$+0.191$	$+0.057$
$N - 2f$				-0.012	$+0.009$	$+0.002$	$+0.001$
$\delta \log r \div \cos (N - f)$				-12	$+9$	$+2$	$+1$

X.—$j = 0$; $j' = 0$.

i'	-1	0	1	2	3	4
i	$+3$	2	1	0	-1	-2
$\frac{1}{4} Duh$	$+0.30$	$+0.77$	$+1.68$	$+0.77$	$+0.30$	$+0.11$
	″	″	″	″	″	″
$\delta\beta \div \sin (N - \lambda)$	$+0.002$	$+0.008$	$+0.030$	$+0.045$	-0.013	-0.002

XI.—$j = -2$; $j' = -1$.

i'	$+2$	3	4	5	6
i	$+1$	0	-1	-2	-3
$De'h$	$+0.43$	$+2.34$	$+2.44$	$+1.72$	$+0.7$
	″	″	″	″	″
$\delta v \div \sin (N - f)$	-0.007	-0.092	$+0.180$	$+0.033$	$+0.008$

XII.—$j = -1$; $j' = -2$.

i'	+2	3	4	5	6
i	+1	0	−1	−2	−3
$De'h$	−0.14	−1.75	−2.00	−1.5	−1.0
	$''$	$''$	$''$	$''$	$''$
$\delta v \div \sin(N - f)$	+0.001	+0.068	−0.148	−0.028	−0.016

XIII.—$j = 0$; $j' = -3$.

i'	+2	3	4	5	6
i	+1	0	−1	−2	−3
$De'h$	+0.02	+0.28	+0.40	+0.30	+0.3
	$''$	$''$	$''$	$''$	$''$
$\delta v \div \sin(N - f)$	0	−0.011	+0.030	+0.006	+0.003

ACTION OF JUPITER.

The direct action of Jupiter is so nearly insignificant that the details of the computation are omitted. The only terms in the longitude exceeding one hundredth of a second, and not sensibly confounded with the elliptic elements of Neptune, are

$$\begin{array}{l} 0''.278 \sin (\lambda' - \lambda) \\ + 0\,.019 \sin 2\, (\lambda' - \lambda) \end{array}$$

ACTION OF VENUS, EARTH, AND MARS.

The only appreciable effect of the attraction of these planets is found in the relation between the radius vector and the mean motion. The coefficients of the perturbative function which correspond to the case when both i' and i are zero introduce changes as below into the secular variation of the longitude of the epoch. Those which correspond to the term in which $N = \lambda' - \omega'$ introduce constants as below into the logarithm of the radius vector. For the sake of completeness we include the similar perturbations produced by Jupiter, Saturn, and Uranus, as already computed:

	$\frac{d\varepsilon}{dt}$	$\delta \log r$
Action of Venus,	$+ 0''.0403$	$- 11$
Earth,	$+ 0\,.0444$	$- 12$
Mars,	$+ 0\,.0059$	$- 2$
Jupiter,	$+ 15\,.3571$	$- 4240$
Saturn,	$+ 4\,.8687$	$- 1344$
Uranus,	$+ 1\,.1261$	$- 311$
Total,	21.4425	$- 5920$

The principal term of $\frac{d\varepsilon}{dt}$, and, indeed, the entire portion not multiplied by the second power of the eccentricity, is

$$\frac{d\varepsilon}{dt} = mn' \left(b^{(0)}_{\frac{1}{2}} + \alpha \frac{db^{(0)}_{\frac{1}{2}}}{d\alpha}\right);$$

while the principal term in $\delta \log r$ is

$$\delta \log r = - \tfrac{1}{2}\, mM \left(b^{(0)}_{\frac{1}{2}} + \alpha D_\alpha b^{(0)}_{\frac{1}{2}}\right).$$

The effect of these terms might, therefore, have been included in the mean distance as a single term, without appreciable error.

§ 14. *Perturbations of Neptune by Saturn through the Sun.*

These perturbations, it will be remembered, have been omitted in the preceding computations, from reasons already set forth. They have been computed by formulæ (16)—(19), and are as follows:

ACTION OF SATURN.

$$\delta v =$$
$$
\begin{aligned}
&- 20''.536 \sin (\lambda' - \lambda) \\
&- 0\,.007 \sin (2\lambda' - 2\lambda - \omega' + \omega) \\
&+ 0\,.530 \sin (-\lambda' + 2\lambda - \omega) \\
&- 0\,.059 \sin (\lambda - \omega') \\
&- 0\,.340 \sin (2\lambda' - \lambda - \omega') \\
&+ 0\,.022 \sin (-\lambda' + 3\lambda - 2\omega) \\
&- 0\,.007 \sin (\lambda' + \lambda - 2\omega) \\
&- 0\,.002 \sin (2\lambda - \omega - \omega')
\end{aligned}
$$

$$\delta \log r =$$
$$
\begin{aligned}
&+ 345 \cos (\lambda' - \lambda) \\
&+ 10 \cos (-\lambda' + 2\lambda - \omega) \\
&- 2 \cos (\lambda - \omega') \\
&+ 3 \cos (2\lambda' - \lambda - \omega')
\end{aligned}
$$

§ 15. *Perturbations of the elements.*—Collecting and adding up the coefficients of all sines or cosines of the same angle in the perturbations, we find them as below. For λ and ω, their values, $l - \tau$ and $\pi - \tau$, are substituted. We shall first collect those terms which are developed as perturbations of the elements, namely, the secular variations, and all terms in the action of Uranus in which $i' = 2\,i$. We find them to be as follows:

$$
\begin{aligned}
\delta h = &+ 125''.67 \sin (2l' - l) \\
&- 0\,.42 \sin (2l' - l - 2\pi) \\
&- 0\,.36 \sin (2l' - l + \pi - \pi') \\
&+ 0\,.14 \sin (2l' - l + \pi' - \pi) \\
&- 30''.93 \sin (4l' - 2l - \pi) \\
&+ 8\,.03 \sin (4l' - 2l - \pi') \\
&- 0\,.03 \sin (4l' - 2l + \pi' - 2\pi) \\
&+ 2''.62 \sin (6l' - 3l - 2\pi) \\
&- 1\,.37 \sin (6l' - 3l - \pi' - \pi) \\
&+ 0\,.17 \sin (6l' - 3l - 2\pi') \\
&+ 0''.0132\, t
\end{aligned}
$$

$$
\begin{aligned}
\delta k = &+ 125''.67 \cos (2l' - l) \\
&+ 0\,.42 \cos (2l' - l - 2\pi) \\
&- 0\,.36 \cos (2l' - l - \pi' + \pi) \\
&+ 0\,.14 \cos (2l' - l + \pi' - \pi) \\
&- 30''.93 \cos (4l' - 2l - \pi) \\
&+ 8\,.03 \cos (4l' - 2l - \pi') \\
&- 0\,.03 \cos (4l' - 2l + \pi' - 2\pi) \\
&+ 2''.62 \cos (6l' - 3l - 2\pi) \\
&- 1\,.37 \cos (6l' - 3l - \pi' - \pi) \\
&+ 0\,.17 \cos (6l' - 3l - 2\pi') \\
&+ 0''.0031\, t
\end{aligned}
$$

$$
\begin{aligned}
\delta l = &+ 2163''.60 \sin (2l' - l - \pi) \\
&- 141\,.69 \sin (2l' - l - \pi') \\
&+ 0\,.56 \sin (2l' - l + \pi' - 2\pi) \\
&+ 0\,.21 \sin (2l' - l + \pi - 2\pi') \\
&+ 1\,.08 \sin (2l' - l + \pi - 2\tau) \\
&- 0\,.08 \sin (2l' - l + \pi' - 2\tau) \\
&- 71''.93 \sin (4l' - 2l - 2\pi) \\
&+ 38\,.09 \sin (4l' - 2l - \pi' - \pi) \\
&- 4\,.99 \sin (4l' - 2l - 2\pi') \\
&+ 4''.36 \sin (6l' - 3l - 3\pi) \\
&- 3\,.27 \sin (6l' - 3l - \pi' - 2\pi) \\
&+ 0\,.85 \sin (6l' - 3l - 2\pi' - \pi) \\
&- 0\,.08 \sin (6l' - 3l - 3\pi') \\
&+ 21''.4425\, t
\end{aligned}
$$

$$
\begin{aligned}
\delta \log a = &- 1232 \cos (2l' - l - \pi) \\
&+ 92 \cos (2l' - l - \pi') \\
&+ 85 \cos (4l' - 2l - 2\pi) \\
&- 44 \cos (4l' - 2l - \pi' - \pi) \\
&+ 6 \cos (4l' - 2l - 2\pi')
\end{aligned}
$$

$$\begin{aligned}\delta p = &- 1''.11 \sin (2l' - l - \pi + \tau) \\ &- 0\,.72 \sin (2l' - l - \pi - \tau) \\ &+ 0\,.16 \sin (2l' - l - \pi' + \tau) \\ &+ 0\,.15 \sin (2l' - l - \pi' - \tau) \\ &- 2''.98 \sin (4l' - 2l - \tau) \\ &+ 0''.0110\, t\end{aligned} \qquad \begin{aligned}\delta q = &- 1''.11 \cos (2l' - l - \pi + \tau) \\ &+ 0\,.72 \cos (2l' - l - \pi - \tau) \\ &+ 0\,.16 \cos (2l' - l - \pi' + \tau) \\ &- 0\,.15 \cos (2l' - l - \pi' - \tau) \\ &- 2''.98 \cos (4l' - 2l - \tau) \\ &+ 0''.0001\, t\end{aligned}$$

§ 16. *Perturbations of the co-ordinates—Comparison with* Peirce *and* Kowalski.—The first column of the following tables gives the coefficients according to Peirce (Proceedings of the American Academy, Vol. 1, pp. 287–291); and the second, the values according to Kowalski (Recherches sur les mouvements de Neptune, pp. 14–16). In the case of Uranus, Peirce's coefficients have been increased by $\frac{1}{6} + \frac{1}{50}$, to reduce his mass of Uranus to the adopted one. The coefficients enclosed in parentheses are not comparable, as they include the effect of terms now developed as perturbations of the elements, and therefore omitted from the perturbations of the co-ordinates. The perturbations of the radius vector have been reduced to logarithms by multiplying by $\frac{0.4342}{30}$.

I.—ACTION OF URANUS.

$\delta v =$ P.	K.	N.	$\delta \log r =$ P.	K.	N.
(−206″.91)	(−244″.40)	$+3''.002 \sin (l' - l)$	(−2284)	(−2289)	$+314 \cos (l' - l)$
+ 10 .24	+ 10 .02	$+9\,.994 \sin 2(l' - l)$	+ 167	+ 163	$+162 \cos 2(l' - l)$
+ 2 .01	+ 2 .02	$+1\,.960 \sin 3(l' - l)$	+ 40	+ 69	$+38 \cos 3(l' - l)$
+ 0 .64	+ 0 .62	$+0\,.610 \sin 4(l' - l)$	+ 14	+ 38	$+13 \cos 4(l' - l)$
+ 0 .25	+ 0 .27	$+0\,.237 \sin 5(l' - l)$	+ 5	+ 23	$+5 \cos 5(l' - l)$
+ 0 .11	+ 0 .35	$+0\,.104 \sin 6(l' - l)$	+ 2	+ 11	$+1 \cos 6(l' - l)$
+ 0 .05	+ 0 .27	$+0\,.041 \sin 7(l' - l)$			
+ 0 .02		$+0\,.017 \sin 8(l' - l)$			
+ 0 .01		$+0\,.007 \sin 9(l' - l)$			
		$+0''.002 \sin (-4l' + 4l - \pi' + \pi)$			
		$+0\,.016 \sin (-3l' + 3l - \pi' + \pi)$			
(− 0.11)	(− 0.73)	$-0\,.103 \sin (-2l' + 2l - \pi' + \pi)$			
(−16.29)	(−16.79)	$-0\,.048 \sin (-l' + l - \pi' + \pi)$			
(+ 0.66)	(+ 0.71)	$+0\,.045 \sin (l' - l - \pi' + \pi)$			
		$-0\,.011 \sin (2l' - 2l - \pi' + \pi)$			
		$+0\,.003 \sin (3l' - 3l - \pi' + \pi)$			
		$+0\,.003 \sin (4l' + 4l - \pi' + \pi)$			
		$+0\,.002 \sin (5l' + 5l - \pi' + \pi)$			
−0.01		$-0''.009 \sin (-5l' + 6l - \pi)$			
−0.01		$-0\,.014 \sin (-4l' + 5l - \pi)$			
−0.02		$-0\,.024 \sin (-3l' + 4l - \pi)$			
−0.04	−0.08	$-0\,.033 \sin (-2l' + 3l - \pi)$			
+0.19	+0.19	$+0\,.183 \sin (-l' + 2l - \pi)$	+2	+ 2	$+3 \cos (-l' + 2l - \pi)$
+0.27	−1.31	$+0\,.274 \sin (l - \pi)$	−5	+11	$-5 \cos (l - \pi)$
		$-0\,.238 \sin (l' - \pi)$			$-10 \cos (l' - \pi)$
(1979.72)	(1955.50)	$+4\,.365 \sin (2l' - l - \pi)$	(−1141)	(−1127)	$+43 \cos (2l' - l - \pi)$
(+69.86)	(+68.73)	$+9\,.563 \sin (3l' - 2l - \pi)$	(+ 693)	(+ 663)	$+58 \cos (3l - 2l - \pi)$
−1.78	−1.78	$-1\,.721 \sin (4l' - 3l - \pi)$	− 28	− 27	$-27 \cos (4l' - 3l - \pi)$
−0.33	−0.59	$-0\,.375 \sin (5l' - 4l - \pi)$	− 7	− 5	$-7 \cos (5l' - 4l - \pi)$
−0.12	−0.29	$-0\,.134 \sin (6l' - 5l - \pi)$	− 3	− 1	$-2 \cos (6l' - 5l - \pi)$
−0.06		$-0\,.057 \sin (7l' - 6l - \pi)$	− 2		$-2 \cos (7l' - 6l - \pi)$
−0.04		$-0\,.022 \sin (8l' - 7l - \pi)$			$-2 \cos (8l' - 7l - \pi)$
−0·01		$-0\,.009 \sin (9l' - 8l - \pi)$			

ACTION OF URANUS (Continued).

$\delta v =$ P.	K.	N.	$\delta \log r =$ P.	K.	N.
		$+0''.001 \sin(-5l'+6l-\pi')$			
		$+0\ .002 \sin(-4l'+5l-\pi')$			
		$-0\ .002 \sin(-3l'+4l-\pi')$			$+1 \cos(-3l'+4l-\pi)$
(−0.01)		$-0\ .015 \sin(-2l'+3l-\pi')$			$-1 \cos(-2l'+3l-\pi)$
(−0.11)		$-0\ .109 \sin(-l'+2l-\pi')$	+ 2		$+2 \cos(-l'+2l-\pi)$
(+2.33)	(+2.65)	$-0\ .177 \sin(l-\pi')$	(− 21)	(− 24)	$+2 \cos(l-\pi)$
		$+0\ .209 \sin(l'-\pi')$			$+5 \cos(l'-\pi)$
(−124.83)	(−132.51)	$-0\ .466 \sin(2l'-l-\pi')$	(+ 95)	(+ 97)	$-13 \cos(2l'-l-\pi)$
(− 17.45)	(− 18.37)	$-2\ .477 \sin(3l'-2l-\pi')$	(−174)	(−184)	$-15 \cos(3l'-2l-\pi)$
+ 0.46	+ 0.53	$+0\ .452 \sin(4l'-3l-\pi')$	+ 7	+ 6	$+9 \cos(4l'-3l-\pi)$
+ 0.11	+ 0.07	$+0\ .101 \sin(5l'-4l-\pi')$	+ 2	+ 1	$+1 \cos(5l'-4l-\pi)$
+ 0.04	− 0.23	$+0\ .027 \sin(6l'-5l-\pi')$		3	$+1 \cos(6l'-5l-\pi)$
+ 0.01		$+0\ .014 \sin(7l'-6l-\pi')$			
		$+0\ .010 \sin(8l'-7l-\pi')$			
		$+0\ .006 \sin(9l'-8l-\pi')$			
		$+0''.002 \sin(3l'-2l+\omega'-2\pi)$			
		$-0\ .016 \sin(4l'-3l+\omega'-2\pi)$			
		$+0\ .002 \sin(5l'-4l+\omega'-2\pi)$			

(The terms in which the constant of the argument is $\pi - 2\pi$, $\pi - 2\tau$, and $\pi - 2\tau'$ are yet smaller, and are neglected.)

P.	K.	N.
		$+0''.017 \sin(-l'+3l-2\pi)$
		$-0\ .001 \sin(2l-2\pi)$
		$-0\ .007 \sin(l'+l-2\pi)$
		$-0\ .009 \sin(2l'-2\pi)$
	(+ 0.75)	$-0\ .151 \sin(3l'-l-2\pi)$
(− 65.45)	(−64.61)	$-0\ .587 \sin(4l'-2l-2\pi)$
(− 5.10)	(− 5.62)	$-1\ .310 \sin(5l'-3l-2\pi)$
		$+0\ .258 \sin(6l'-4l-2\pi)$
		$+0\ .061 \sin(7l'-5l-2\pi)$
		$+0\ .027 \sin(8l'-6l-2\pi)$
		$+0\ .010 \sin(9l'-7l-2\pi)$
		$+0\ .004 \sin(10l'-8l-2\pi)$
		$+0''.005 \sin(l'+l-\pi'-\pi)$
		$+0\ .006 \sin(2l'-\pi'-\pi)$
(+16.08)	(+17.01)	$+0\ .098 \sin(3l'-l-\pi'-\pi)$
(+33.73)	(+36.67)	$+0\ .366 \sin(4l'-2l-\pi'-\pi)$
(+ 2.56)	(+ 3.35)	$+0\ .688 \sin(5l'-3l-\pi'-\pi)$
		$-0\ .136 \sin(6l'-4l-\pi'-\pi)$
		$-0\ .032 \sin(7l'-5l-\pi'-\pi)$
		$-0\ .019 \sin(8l'-6l-\pi'-\pi)$
		$-0\ .010 \sin(9l'-7l-\pi'-\pi)$
		$-0\ .005 \sin(10l'-8l-\pi'-\pi)$
		$-0''.003 \sin(2l-2\pi')$
		$-0\ .011 \sin(l'+l-2\pi')$
(−1.04)	(−1.15)	$+0\ .005 \sin(3l'-l-2\pi')$
(−4.29)	(−4.79)	$-0\ .046 \sin(4l'-2l-2\pi')$
(−0.33)	(−0.21)	$-0\ .090 \sin(5l'-3l-2\pi')$
		$+0\ .020 \sin(6l'-4l-2\pi')$
		$+0\ .005 \sin(7l'-5l-2\pi')$
		$+0\ .002 \sin(8l'-6l-2\pi')$
		$-0''.003 \sin(l'+l-2\tau)$
		$-0\ .016 \sin(3l'-l-2\tau)$
		$-0\ .022 \sin(4l'-2l-2\tau)$
		$-0\ .041 \sin(5l'-3l-2\tau)$
		$+0\ .006 \sin(6l'-4l-2\tau)$

Latitude.

$\delta\beta =$ N.
$-0''.004 \sin(-4l'+5l-\tau)$
$-0\ .008 \sin(-3l'+4l-\tau)$
$-0\ .023 \sin(-2l'+3l-\tau)$
$-0\ .056 \sin(-l'+2l-\tau)$
$+0\ .040 \sin(l-\tau)$
$+0\ .106 \sin(l'-\tau)$
$+0\ .320 \sin(2l'-l-\tau)$
$+0\ .060 \sin(3l'-2l-\tau)$
$-0\ .063 \sin(4l'-3l-\tau)$
$-0\ .016 \sin(5l'-4l-\tau)$
$-0\ .005 \sin(6l'-5l-\tau)$
$-0\ .004 \sin(7l'-6l-\tau)$

II.—ACTION OF SATURN.

		$\delta v =$			$\delta \log r =$
P.	K.	N.	P.	K.	N.
$-18''.60$	$-18''.12$	$-18''.552 \sin (l' - l)$	$+398$	$+393$	$+397 \cos (l' - l)$
$+0.15$	$+0.15$	$+0.141 \sin 2(l' - l)$	$+4$	0	$+4$
$+0.02$	$+0.03$	$+0.012 \sin 3(l' - l)$			
	$+0.06$	$+0.000 \sin 4(l' - l)$			
		$+0''.002 \sin (-l' + l - \pi' + \pi)$			
		$-0.006 \sin (2l' - 2l - \pi' + \pi)$			
$+0.54$	$+0.53$	$+0''.524 \sin (-l' + 2l - \pi)$	$+12$	$+11$	$+9 \cos (-l' + 2l - \pi)$
$+0.01$	-0.16	$+0.008 \sin (l - \pi)$		-2	$+2 \cos (l - \pi)$
		$+1.319 \sin (l' - \pi)$			$-34 \cos (l' - \pi)$
-0.28	$+1.09$	$-0.280 \sin (2l' - l - \pi)$	-6	-20	$-7 \cos (2l' - l - \pi)$
-0.02	-0.17	$-0.023 \sin (3l' - 2l - \pi)$			$-1 \cos (3l' - 2l - \pi)$
		$-0.004 \sin (4l' - 3l - \pi)$			
-0.08	-0.09	$-0''.080 \sin (l - \pi')$	-3	-3	$-1 \cos (l - \pi')$
		$+0.136 \sin (l' - \pi')$			
-0.22	$+3.85$	$-0.228 \sin (2l' - l - \pi')$	$+3$	$+47$	$+5 \cos (2l' - l - \pi')$
$+0.01$	$+0.04$	$+0.008 \sin (3l' - 2l - \pi')$			
		$+0.001 \sin (4l' - 3l - \pi')$			
		$+0''.022 \sin (-l' + 3l - 2\pi)$			
	$+0.10$	$-0.008 \sin (l' + l - 2\pi)$			
		$+0.004 \sin (2l' - 2\pi)$			
	$+0.13$	$+0.037 \sin (3l' - l - 2\pi)$			
		$-0''.002 \sin (2l - \pi' - \pi)$			
		$-0.002 \sin (l' + l - \pi' - \pi)$			
		$+0.020 \sin (2l' - \pi' - \pi)$			
	$+0.10$	$-0.029 \sin (3l' - l - \pi' - \pi)$			
		$+0''.005 \sin (2l' - 2\pi')$			
	-0.75	$+0.006 \sin (3l' - l - 2\pi')$			

$\delta\beta =$
$+0''.309 \sin (l - \tau)$
$+0.045 \sin (l' - \tau)$
$-0.005 \sin (2l' - l - \tau)$

III.—ACTION OF JUPITER.

		$\delta v =$			$\delta \log r =$
P.	K.	N.	P.	K.	N.
$-34''.09$	$-32''.67$	$-34''.121 \sin (l' - l)$	$+719$	$+683$	$+701 \cos (l' - l)$
$+0.02$	$+0.03$	$+0.019 \sin 2(l' - l)$		0	$+1 \cos 2(l' - l)$
	-0.14	$+0.003 \sin 3(l' - l)$			
	$+0.11$	$-0.009 \sin (2l' - 2l - \pi' + \pi)$			
$+0.82$	$+0.84$	$+0''.801 \sin (-l' + 2l - \pi)$	$+17$	$+17$	$+18 \cos (-l' + 2l + \pi)$
	-0.07	$+0.003 \sin (l - \pi)$			$+51 \cos (-l' - \pi)$
		$+2.358 \sin (l' - \pi)$			
-0.01	$+0.19$	$-0.010 \sin (2l' - l - \pi)$			
-0.14	-0.15	$-0''.143 \sin (l - \pi')$	-6	-27	$-2 \cos (l - \pi')$
		$+0.117 \sin (l' - \pi')$			$-2 \cos (l' - \pi')$
-0.42	-0.48	$-0.432 \sin (2l' - l - \pi')$	$+6$	$+135$	$+7 \cos (2l' - l - \pi')$

ACTION OF JUPITER (Continued).

$\delta v =$			$\delta \log r =$		
P.	K.	N.	P.	K.	N.
		$+0''.030 \sin(-l'+3l-2\pi)$			
		$-0\ .011 \sin(l'+l-2\pi)$			
		$+0\ .004 \sin(2l'-2\pi)$			
	$+0.10$	$-0''.005 \sin(2l-\pi'-\pi)$			
		$+0\ .028 \sin(2l'-\pi'-\pi)$			
		$\delta\beta =$			
		$+0''.564 \sin(l-\tau)$			
		$+0\ .039 \sin(l'-\tau)$			

By comparing the different authorities for the coefficients, it will be seen that while our present results agree very well with those of Professor Peirce, the agreement with Professor Kowalski is in many cases very far from being satisfactory. It will be observed that the latter differ most in the case of those terms whose coefficients depend on the action of the disturbing planets on the Sun, and we have also seen that these terms are ordinarily developed as small differences of very large quantities. They are, therefore, the terms into which errors would most easily creep.

The terms enclosed in parentheses are not of great importance, because they are for a long period sensibly confounded with the elliptic elements. Notwithstanding that one of these terms amounts to more than half a degree, and others to several minutes, the effect of the whole of them could scarcely be discovered from all the observations hitherto made on Neptune.

§ 17. For the purpose of tabulating and computing an ephemeris, it is expedient to change the form of the perturbations by Uranus. Consider any two terms in which the coefficients of l are equal, but of opposite signs:

$$\delta v = p_1 \sin\{sl' - iA - \omega\} + p_2 \sin\{sl' + iA - \omega\}$$

where

$$A = l' - l$$

The terms may then be put in the form

$$\{(p_2 - p_1)\sin\omega \sin iA + (p_2 + p_1)\cos\omega\cos iA\}\sin sl'$$
$$\{(p_2 - p_1)\cos\omega \sin iA - (p_2 + p_1)\sin\omega\cos iA\}\cos sl'$$

So that we may put

$$\delta v = \delta v_o + P_{s.1}\sin l' + P_{c.1}\cos l' + P_{s.2}\sin 2l' + P_{c.2}\cos 2l'$$
$$\delta \log r = \delta \log r_o + R_{s.1}\sin l' + P_{c.1}\cos l'$$

where δv, P, and R are functions only of A, and may be tabulated as such.

§ 18. For Jupiter and Saturn, if we neglect those terms of which the coefficients are less than $0''.03$, it will be more convenient to tabulate the perturbations directly. This course we shall adopt, except with reference to those perturbations which depend on the mean longitude of Neptune alone, and do not contain the mean longitude of the disturbing planets. These have been omitted by both

Peirce and Kowalski, as may be seen by reference to the preceding values of their coefficients. They are, in fact, very nearly confounded with the elliptic motion of the planet, but not exactly. We shall, at present, retain only the small residuals, after subducting those portions which are sensibly elliptic. The entire terms are as follows:

1. In the longitude.

Action of Uranus,	$+0''.385 \sin l$	$-0''.092 \cos l$	$-0''.014 \sin 2l$	$-0''.002 \cos 2l$	
Saturn,	$+0\ .099 \sin l$	$-1\ .412 \cos l$	$-0\ .018 \sin 2l$	$-0\ .020 \cos 2l$	
Jupiter,	$+2\ .393 \sin l$	$-0\ .567 \cos l$	$+0\ .018 \sin 2l$	$-0\ .029 \cos 2l$	
Total,	$+2\ .877 \sin l$	$-2\ .071 \cos l$	$-0\ .014 \sin 2l$	$-0\ .051 \cos 2l$	(a)

2. In the logarithm of radius vector.

Action of Uranus,	$+\ 1 \sin l$	$+14 \cos l$	
Saturn,	$-34 \sin l$		
Jupiter,	$-11 \sin l$	$-51 \cos l$	
Total,	$-44 \sin l$	$-37 \cos l$	(b)

Changes in the functions $e \sin \pi$ and $e \cos \pi$, represented by δh and δk, will produce the following changes in the longitude and log r,

$$\delta v = 2\,\delta k \sin l - 2\,\delta h \cos l + \tfrac{5}{2}\,(k\delta k - h\delta h) \sin 2l - \tfrac{5}{2}\,(k\delta h + h\delta k) \cos 2l$$
$$\delta \log r = -M\delta h \sin l - M\delta k \cos l.$$

Taking the elliptic terms to be subducted so that the coefficients of $\sin l$ and $\cos l$ shall vanish, we must put

$$\delta h = +1''.036\,;\quad \delta k = +1''.438,$$

which will produce the inequalities

$$\delta v = +\,2''.877 \sin l - 2''.071 \cos l + 0''.007 \sin 2l - 0''.037 \cos 2l$$
$$\delta \log r = -\ 21 \sin l - \ 30 \cos l.$$

Subtracting these elliptic inequalities from (a) and (b), we have for the residuals

$$\delta v = -\,0''.021 \sin 2l - 0''.014 \cos 2l$$
$$\delta \log r = -\ 23 \sin l - \ 7 \cos l.$$

So that the constants of P_s, etc. are

$$\begin{aligned}
\text{Constant of } P_{s.1} &= 0 \\
P_{c.1} &= 0 \\
P_{s.2} &= -0''.021 \\
P_{c.2} &= -0\ .014 \\
R_{s.1} &= -\ 23 \\
R_{c.1} &= -\ 7
\end{aligned}$$

The constant terms in the coefficients $B_{s.1}$ and $B_{c.1}$, which give the perturbations of the latitude, may be omitted without any error amounting to one hundredth of a second.

§ 19. The form of the preceding perturbations being different from that of the perturbations computed by Professor Peirce, the elliptic elements are next provisionally altered, so that the provisional theory shall be substantially identical with that already adopted. Small corrections have also been applied to the constants which determine the plane of the orbit.

The provisional elements finally adopted for correction are as follows:

$$
\begin{aligned}
\varepsilon &= 335^\circ\ 5'\ 25''.97 \\
n &= 7864''.421 \\
h &= +1192''.93 \\
k &= +1279''.36 \\
p &= +4910''.17 \\
q &= -4137''.46
\end{aligned}
$$

Epoch, 1850, Jan. 0, Greenwich mean noon. Unit of time, 365.25 days.

$e =$	0.00848055
e (in seconds)	1749″.24
i	1° 47′ 1″.95
π	42 59 52 .0
Ω	130 7 6 .7
$\log a$	1.4787523

The perturbations of the preceding elements are expressed in the following form:

Put $\qquad M = 2\,l' - l$

$T =$ Number of centuries after 1850, Jan. 0.

Then, $\qquad M = 281^\circ\ 43'\ 48'' + 8^\circ\ 26'\ 10''.7\ T;$

and

$$
\begin{aligned}
\delta h = {} & 125''.42 \sin(M - 0^\circ\ 16'.3) \\
& + 36''.08 \sin(2M + 1^\circ\ 50') \\
& + 3''.58 \sin(3M + 3^\circ\ 42') \\
& + 1''.32\ T + \text{constant.}
\end{aligned}
\qquad
\begin{aligned}
\delta k = {} & 126''.17 \cos(M - 0^\circ\ 6'.2) \\
& + 36''.08 \cos(2M + 1^\circ\ 50') \\
& + 3''.58 \cos(3M + 3^\circ\ 42') \\
& + 0''.31\ T + \text{constant.}
\end{aligned}
$$

$$
\begin{aligned}
\delta l = {} & 2247''.52 \sin(M - 170^\circ\ 32'\ 23'') \\
& + 98''.57 \sin(2M + 183^\circ\ 24'.1) \\
& + 6''.81 \sin(3M + 186^\circ\ 14') \\
& + 2144''.26\ T + \text{const.} + \text{const.} \times T.
\end{aligned}
\qquad
\begin{aligned}
\delta \log a = {} & 1286 \cos(M + 9^\circ\ 8') \\
& + 115 \cos(2M + 4^\circ\ 0') \\
& + \text{constant.}
\end{aligned}
$$

$$
\begin{aligned}
\delta p = {} & 1''.86 \sin M \\
& + 2''.98 \sin(2M - 155^\circ\ 38') \\
& + 1''.10\ T + \text{constant.}
\end{aligned}
\qquad
\begin{aligned}
\delta q = {} & 0''.87 \cos(M - 61^\circ\ 0') \\
& + 2''.98 \cos(2M - 155^\circ\ 38') \\
& + 0''.01\ T + \text{constant.}
\end{aligned}
$$

The constants being so taken that the perturbations, and also the differential coefficient of δl, shall all vanish at the epoch 1850.0. These perturbations are given for the beginning of every tenth year, from 1600 to 2000, in the following table:

Secular and Long-Period Perturbations of the Elements of Neptune from 1600 to 2000.

Date	δl	$\delta \log a$	δh	δk	δp	δq	$\delta p'$	$\delta q'$
	″		″	″	″	″	″	″
1600	−149.21	−473	+22.33	−45.28	−4.68	+0.79	+8.58	−116.52
10	137.63	455	21.18	43.85	4.48	0.79	8.29	111.82
20	126.50	437	20.05	42.39	4.29	0.78	7.99	107.12
30	115.83	418	18.94	40.90	4.10	0.77	7.69	102.42
40	105.62	400	17.85	39.37	3.90	0.76	7.39	97.73
50	−95.88	−381	+16.77	−37.81	−3.71	+0.75	+7.09	−93.04
60	86.60	362	15.71	36.22	3.52	0.73	6.78	88.36
70	77.78	344	14.67	34.60	3.32	0.71	6.47	83.68
80	69.42	325	13.65	32.94	3.13	0.69	6.15	79.00
90	61.52	307	12.66	31.25	2.94	0.67	5.83	74.33
1700	−54.09	−288	+11.69	−29.53	−2.75	+0.64	+5.50	−69.66
10	47.13	269	10.74	27.77	2.56	0.61	5.17	64.99
20	40.65	250	9.81	25.99	2.37	0.58	4.84	60.32
30	34.65	231	8.90	24.17	2.18	0.55	4.49	55.66
40	29.13	212	8.01	22.33	2.00	0.52	4.14	51.01
50	−24.09	−193	+7.14	−20.45	−1.81	+0.48	+3.79	−46.36
60	19.52	174	6.30	18.54	1.62	0.44	3.43	41.71
70	15.43	154	5.48	16.60	1.44	0.40	3.08	37.06
80	11.81	135	4.69	14.63	1.25	0.35	2.71	32.42
90	8.68	115	3.93	12.62	1.07	0.30	2.34	27.79
1800	−6.03	−96	+3.20	−10.59	−0.89	+0.25	+1.96	−23.15
10	3.86	77	2.50	8.53	0.71	0.20	1.58	18.52
20	2.17	57	1.83	6.44	0.53	0.15	1.20	13.88
30	0.96	38	1.19	4.32	0.35	0.10	0.81	9.25
40	−0.24	−19	+0.58	−2.17	−0.17	+0.05	+0.41	−4.63
50	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00
60	−0.24	+19	−0.54	+2.20	+0.17	0.06	−0.41	+4.62
70	0.96	38	1.04	4.42	0.34	0.11	0.82	9.25
80	2.17	57	1.51	6.68	0.51	0.17	1.24	13.87
90	3.86	77	1.93	8.96	0.68	0.23	1.67	18.48
1900	−6.03	+96	−2.32	+11.26	+0.85	−0.29	−2.10	+23.09
10	8.68	115	2.67	13.59	1.01	0.35	2.54	27.70
20	11.81	133	2.98	15.94	1.17	0.42	2.98	32.30
30	15.44	152	3.25	18.31	1.33	0.49	3.43	36.90
40	19.53	171	3.47	20.70	1.48	0.56	3.89	41.49
50	−24.10	+190	−3.65	+23.11	+1.64	−0.63	−4.35	+46.09
60	29.14	209	3.79	25.54	1.80	0.70	4.81	50.69
70	34.66	227	3.89	27.99	1.95	0.77	5.28	55.28
80	40.66	246	3.94	30.46	2.11	0.84	5.75	59.88
90	47.13	265	3.94	32.95	2.26	0.91	6.23	64.47
2000	−54.09	+284	−3.89	+35.46	+2.42	−0.98	−6.71	+69.06

δp and δq refer to the fixed ecliptic of 1850.0, $\delta p'$ and $\delta q'$ to the movable ecliptic of the date, the motion being that adopted in Hansen's "Tables du Soleil," and concluded from the secular diminution of the obliquity there given.

The corrections to the true longitude, latitude, and radius vector derived from the pure elliptic elements require corrections for these perturbations as follows:

$$\delta v = \frac{dv}{dl}\,\delta l + \frac{dv}{dh}\,\delta h + \frac{dv}{dk}\,\delta k,$$

$$\delta \log r = \delta \log a + \frac{d\log r}{dh}\,\delta h + \frac{d\log r}{dk}\,\delta k,$$

$$\delta \beta = \frac{d\beta}{dp}\,\delta p + \frac{d\beta}{dq}\,\delta q.$$

For the period during which Neptune has been observed, we have, to a sufficient degree of approximation,

$$\frac{dv}{dl} = 1,$$

$$\frac{dv}{dh} = -2\cos l, \qquad \frac{dv}{dk} = 2\sin l;$$

$$\frac{d\log r}{dh} = -M\sin l, \qquad \frac{d\log r}{dk} = -M\cos l;$$

$$\frac{d\beta}{dp} = -\cos v, \qquad \frac{d\beta}{dq} = \sin v.$$

The values of $P_{s.1}$, $P_{c.1}$, etc., derived from the perturbations by Uranus, are, putting $A =$ mean longitude of Uranus, minus that of Neptune,

$P_{s.1} =$	$-0''.683 \sin A$	$-5''.000 \cos A$	$P_{c.1} =$	$+4''.208 \sin A$	$-0''.559 \cos A$
	$-0\ .400 \sin 2A$	$-11\ .410 \cos 2A$		$+10\ .892 \sin 2A$	$-0\ .330 \cos 2A$
	$+0\ .044 \sin 3A$	$+2\ .031 \cos 3A$		$-1\ .989 \sin 3A$	$+0\ .078 \cos 3A$
	$+0\ .006 \sin 4A$	$+0\ .462 \cos 4A$		$-0\ .418 \sin 4A$	$+0\ .018 \cos 4A$
	$+0\ .009 \sin 5A$	$+0\ .165 \cos 5A$		$-0\ .135 \sin 5A$	$+0\ .013 \cos 5A$
	$+0\ .001 \sin 6A$	$+0\ .076 \cos 6A$		$-0\ .056 \sin 6A$	$+0\ .003 \cos 6A$
	$-0\ .003 \sin 7A$	$+0\ .035 \cos 7A$		$-0\ .023 \sin 7A$	
	$-0\ .002 \sin 8A$	$+0\ .017 \cos 8A$		$-0\ .009 \sin 8A$	
	$-0\ .002 \sin 9A$	$+0\ .008 \cos 9A$		$-0\ .004 \sin 9A$	
	$-0\ .001 \sin 10A$	$+0\ .004 \cos 10A$		$-0\ .002 \sin 10A$	

$P_{s.2} =$	$-0''.021$		$P_{c.2} =$	$-0''.014$	
	$-0\ .254 \cos A$	$-0''.038 \sin A$		$-0\ .022 \cos A$	$+0''.228 \sin A$
	$-0\ .867 \cos 2A$	$-0\ .035 \sin 2A$		$-0\ .027 \cos 2A$	$+0\ .863 \sin 2A$
	$-1\ .821 \cos 3A$	$-0\ .147 \sin 3A$		$-0\ .135 \cos 3A$	$+1\ .849 \sin 3A$
	$+0\ .355 \cos 4A$	$+0\ .023 \sin 4A$		$+0\ .025 \cos 4A$	$-0\ .355 \sin 4A$
	$+0\ .083 \cos 5A$	$+0\ .006 \sin 5A$		$+0\ .008 \cos 5A$	$-0\ .085 \sin 5A$
	$+0\ .039 \cos 6A$			$+0\ .002 \cos 6A$	$-0\ .041 \sin 6A$
	$+0\ .018 \cos 7A$				$-0\ .018 \sin 7A$
	$+0\ .008 \cos 8A$				$-0\ .008 \sin 8A$
	$+0\ .004 \cos 9A$				$-0\ .004 \sin 9A$

$R_{s.1} =$	-23		$R_{c.1} =$	-7	
		$-58 \sin A$		$-46 \cos A$	
	$+4 \cos 2A$	$-66 \sin 2A$		$-70 \cos 2A$	
		$+34 \sin 3A$		$+32 \cos 3A$	$-1 \sin 3A$
		$+7 \sin 4A$		$+9 \cos 4A$	$+2 \sin 4A$
		$+3 \sin 5A$		$+3 \cos 5A$	
		$+2 \sin 6A$		$+2 \cos 6A$	

$B_{s.1} =$	$+0''.328 \cos A$	$+0''.116 \sin A$	$B_{c.1} =$	$+0''.148 \cos A$	$-0''.256 \sin A$
	$+0\ .005 \cos 2A$	$+0\ .048 \sin 2A$		$+0\ .002 \cos 2A$	$-0\ .105 \sin 2A$
	$-0\ .078 \cos 3A$	$-0\ .017 \sin 3A$		$-0\ .035 \cos 3A$	$+0\ .036 \sin 3A$
	$-0\ .022 \cos 4A$	$-0\ .003 \sin 4A$		$-0\ .009 \cos 4A$	$+0\ .008 \sin 4A$
	$-0\ .009 \cos 5A$			$-0\ .004 \cos 5A$	
	$-0\ .006 \cos 6A$				

The other terms in the longitude, logarithm of r, and latitude, representing the mean longitude of the planet by the initial letter of its name, are:

$$
\begin{array}{llll}
\delta v_o = & -2''.949 \sin A & -0''.002 \cos A \\
& -9\ .942 \sin 2A & -0\ .094 \cos 2A \\
& -1\ .967 \sin 3A & +0\ .016 \cos 3A \\
& -0\ .610 \sin 4A & +0\ .004 \cos 4A \\
& -0\ .237 \sin 5A \\
& -0\ .104 \sin 6A \\
& -0\ .041 \sin 7A \\
& -0\ .017 \sin 8A \\
& -0\ .007 \sin 9A \\
& +18''.552 \sin (S-N) \\
& -\ 0\ .137 \sin 2(S-N) \\
& -\ 0\ .012 \sin 3(S-N) \\
& & -0''.524 \cos (2S-N) \\
& -\ 0\ .058 \sin S & +0\ .047 \cos S \\
& +\ 0\ .166 \sin (S-2N) & -0\ .436 \cos (S-2N) \\
& +34\ .121 \sin (J-N) \\
& -\ 0\ .011 \sin 2(J-N) \\
& +\ 0\ .783 \sin (2J-N) & -0\ .164 \cos (2J-N) \\
& -\ 0\ .101 \sin J & +0\ .097 \cos J \\
& +\ 0\ .326 \sin (J-2N) & +0\ .297 \cos (J-2N)
\end{array}
$$

$$
\begin{array}{lll}
\delta r_o = & 314 \cos A \\
& +162 \cos 2A \\
& +\ 38 \cos 3A \\
& +\ 13 \cos 4A \\
& +\ 5 \cos 5A \\
& +\ 2 \cos 6A \\
& +397 \cos (S-N) \\
& +\ 4 \cos 2(S-N) \\
& +\ 10 \sin (2S-N) & +\ 1 \cos (2S-N) \\
& +\ 4 \sin (S-2N) & +\ 4 \cos (S-2N) \\
& & +701 \cos (J-N) \\
& +\ 4 \sin (2J-N) & +\ 18 \cos (2J-N) \\
& -\ 5 \sin (J-2N) & +\ 4 \cos (J-2N)
\end{array}
$$

$$\delta\beta_o = -0''.302 \sin S + 0''.065 \cos S + 0''.041 \sin J + 0''.563 \cos J.$$

It will be observed that in the perturbations of the longitude by Jupiter and Saturn we have neglected a number of small terms, the coefficients of the four largest of which are each about 0''.03. The probable error in the theory produced by this neglect is 0''.04, and it was judged best, therefore, not to encumber it with them. But, should any one wish to include their effect, it can readily be calculated. Then, we have

Provisional longitude of Neptune, referred to the mean equinox

= Precession, + Longitude in pure elliptic orbit, from elements page 39

$$+\delta l + (P_{s.1} + 2\,\delta k) \sin l + (P_{c.1} - 2\,\delta h) \cos l + P_{s.2} \sin 2\,l + P_{c.2} \cos 2\,l + \delta v_o$$

+ Reduction to ecliptic.

Common logarithm of the radius vector

= Log. radius vector in elliptic orbit

$$-.0005920 + \delta a + (R_{s.1} - M\delta h) \sin l + (R_{c.1} - M\delta k) \cos l + \delta r_o.$$

Latitude =

Latitude in elliptic orbit (the longitude being increased by the perturbations),

$$+ (B_{s.1} + \delta q) \sin v + (B_{c.1} - \delta p) \cos v + \delta\beta_o.$$

l is the mean longitude of Neptune, and v its true longitude in orbit, referred to the mean equinox of 1850.0.

§ 20. These formulæ give the following heliocentric positions of Neptune:

Heliocentric co-ordinates of Neptune, referred to the mean equinox of date, for each 180th day, Greenwich mean noon.

Date.		Longitude.	Latitude.	log *r*.
		° ′ ″	° ′ ″	
1795,	May 9,	215 5 20.12	+1 47 59.80	1.4817427
1846,	Jan. 21,	325 28 41.54	—0 28 26.90	1.4774075
	July 20,	326 33 58.15	0 30 23.48	3215
1847,	Jan. 16,	327 39 13.82	0 32 19.44	2356
	July 15,	328 44 28.74	0 34 14.63	1510
1848,	Jan. 11,	329 49 43.21	0 36 9.15	1.4770685
	July 9,	330 54 57.50	—0 38 2.92	1.4769892
1849,	Jan. 5,	332 0 11.98	0 39 55.91	9135
	July 4,	333 5 27.14	0 41 48.06	8420
	Dec. 31,	334 10 43.37	0 43 39.37	7742
1850,	June 29,	335 16 1.07	0 45 29.78	7104
	Dec. 26,	336 21 20.50	—0 47 19.25	6503
1851,	June 24,	337 26 42.10	0 49 7.76	5935
	Dec. 21,	338 32 6.10	0 50 55.27	5396
1852,	June 18,	339 37 32.77	0 52 41.71	4880
	Dec. 15,	340 43 2.18	0 54 27.04	4383
1853,	June 13,	341 48 34.62	—0 56 11.23	3895
	Dec. 10,	342 54 10.02	0 57 54.26	3405
1854,	June 8,	343 59 48.28	0 59 36.04	2907
	Dec. 5,	345 5 29.19	1 1 16.58	2395
1855,	June 3,	346 11 12.34	1 2 55.79	1856
	Nov. 30,	347 16 57.47	—1 4 33.67	1281
1856,	May 28,	348 22 43.95	1 6 10.17	0671
	Nov. 24,	349 28 31.22	1 7 45.23	1.4760028
1857,	May 23,	350 34 18.63	1 9 18.83	1.4759357
	Nov. 19,	351 40 5.78	1 10 50.93	8652
1858,	May 18,	352 45 52.17	—1 12 21.48	7918
	Nov. 14,	353 51 37.46	1 13 50.50	7185
1859,	May 13,	354 57 21.65	1 15 17.89	6454
	Nov. 9,	356 3 4.60	1 16 43.65	5739
1860,	May 7,	357 8 46.65	1 18 7.79	5049
	Nov. 3,	358 14 27.84	—1 19 30.24	4394
1861,	May 2,	359 20 8.66	1 20 50.95	3779
	Oct. 29,	0 25 49.45	1 22 9.96	3210
1862,	April 27,	1 31 30.52	1 23 27.19	2691
	Oct. 24,	2 37 12.30	1 24 42.64	2220
1863,	April 22,	3 42 55.16	—1 25 56.24	1797
	Oct. 19,	4 48 39.57	1 27 7.97	1423
1864,	April 16,	5 54 25.74	1 28 17.84	1093
	Oct. 13,	7 0 14.10	1 29 25.77	0801
1865,	April 11,	8 6 4.93	—1 30 31.79	1.4750547

From these heliocentric positions are concluded the following *apparent* geocentric positions, corrected for aberration, for the dates of the normal places to be given in the next chapter.

Date.		Geocentric Longitude.	Geocentric Latitude.	Date.		Geocentric Longitude.	Geocentric Latitude.
		° ′ ″	° ′ ″			° ″	° ′ ″
1795,	May 9,	214 37 19.1	+1 50 34.4	1856,	Aug. 8,	349 54 3.3	−1 8 44.8
1846,	Oct. 14,	325 31 34.9	−0 31 56.0		Sept. 13,	348 58 37.4	1 9 27.2
	Nov. 14,	325 23 23.2	0 31 44.0		Oct. 26,	347 56 48.8	1 9 8.2
1847,	July 26,	329 41 22.0	−0 35 25.9		Nov. 17,	347 40 53.1	1 8 35.3
	Aug. 17,	329 7 18.3	0 35 47.7	1857,	Aug. 13,	352 5 16.5	−1 12 6.2
	Oct. 8,	327 52 10.4	0 35 58.8		Sept. 21,	351 4 2.0	1 12 46.1
	Nov. 18,	327 36 56.3	0 35 38.6		Oct. 24,	350 16 9.6	1 12 28.3
1848,	July 25,	331 58 5.0	−0 39 22.8		Dec. 8,	349 54 1.4	1 11 11.8
	Aug. 29,	331 3 15.8	0 39 55.2	1858,	Aug. 18,	354 23 52.6	−1 15 21.0
	Oct. 6,	330 8 55.3	0 39 57.8		Sept. 23,	353 19 17.2	1 15 56.6
	Nov. 17,	329 49 22.4	0 39 32.8		Oct. 28,	352 28 49.2	1 15 34.8
1849,	Sept. 1,	333 15 38.6	−0 43 52.7		Dec. 12,	352 8 46.7	1 14 11.8
	Oct. 15,	332 15 32.4	0 43 49.2	1859,	Aug. 21,	356 30 2.9	−1 18 25.8
	Nov. 25,	332 4 16.7	0 43 17.1		Sept. 23,	355 37 44.6	1 19 0.0
1850,	Aug. 28,	335 39 38.5	−0 47 42.7		Nov. 8,	354 34 29.4	1 18 23.0
	Oct. 15,	334 31 9.5	0 47 41.1		Dec. 14,	354 22 52.5	1 17 9.3
	Nov. 20,	334 15 23.8	0 47 9.5	1860,	Aug. 20,	358 47 48.1	−1 21 17.7
1851,	Sept. 2,	337 48 58.1	−0 51 33.7		Sept. 21,	357 54 28.1	1 21 56.4
	Oct. 14,	336 48 10.9	0 51 30.0		Oct. 31,	356 58 22.4	1 21 32.2
	Nov. 20,	336 28 31.0	0 50 54.1		Dec. 13,	356 36 24.7	1 20 4.6
1852,	Aug. 7,	340 46 11.0	−0 54 51.6	1861,	Aug. 22,	1 2 42.4	−1 24 6.0
	Sept. 5,	340 0 10.3	0 55 19.5		Sept. 18,	0 21 7.6	1 24 42.2
	Oct. 12,	339 5 43.0	0 55 14.8		Oct. 30,	359 16 38.4	1 24 24.6
	Nov. 28,	338 43 23.4	0 54 23.3		Dec. 7,	358 50 3.3	1 23 7.9
1853,	Sept. 1,	342 24 47.7	−0 58 55.9	1862,	Aug. 24,	3 17 34.7	−1 26 46.7
	Oct. 15,	341 19 0.2	0 58 52.4		Sept. 23,	2 31 7.7	1 27 25.7
	Nov. 24,	340 56 3.0	0 58 4.7		Nov. 6,	1 25 26.1	1 26 57.3
1854,	Aug. 30,	344 46 17.8	−1 2 27.5		Dec. 15,	1 4 10.0	1 25 30.0
	Sept. 24,	344 5 33.2	1 2 37.0	1863,	Aug. 28,	5 29 46.2	−1 29 23.7
	Oct. 27,	343 23 17.3	1 2 15.3		Sept. 27,	4 42 49.6	1 30 0.3
	Dec. 5,	343 12 2.8	1 1 19.1		Nov. 17,	3 30 58.0	1 29 12.5
1855,	Aug. 10,	347 34 54.2	−1 5 28.0		Dec. 12,	3 18 18.2	1 28 12.4
	Sept. 8,	346 49 57.0	1 6 1.8	1864,	Aug. 7,	8 9 20.6	−1 30 53.7
	Oct. 22,	345 45 6.2	1 5 50.1		Oct. 1,	6 52 56.7	1 32 27.0
	Nov. 29,	345 24 25.3	−1 4 54.8		Nov. 12,	5 51 37.8	1 31 49.1
					Dec. 17,	5 32 27.7	−1 30 23.1

The next step is to deduce positions of Neptune from observations, in order to compare them with the above theoretical positions.

CHAPTER III.

DISCUSSION OF THE OBSERVATIONS OF NEPTUNE.

§ 21. During the four years following the discovery of Neptune, observations of this planet, both meridian and extra-meridian, were very numerous. If the results of all these observations were free from constant errors, and, therefore, strictly comparable both with themselves and with subsequent observations, their combination would give very accurate positions of the planet. Unfortunately, however, we cannot assume that observations of different kinds, made at different observatories, are strictly comparable, nor have we, in many cases, the data for reducing them to a common standard.

Let us consider, for instance, the meridian observations. Under the title of "Meridian Observations of Neptune," we find in astronomical periodicals series of observed Right Ascensions and Declinations. But right ascensions and declinations can never be really observed with any instrument. Only times of transit, and the readings of micrometers and other instruments, are really observed. The right ascensions and declinations of the planet are concluded from the observations, by the aid of a great number of subsidiary data, some relating to the stars, others to the instrument. Respecting these data we have, in most cases, absolutely no information whatever. But a knowledge of some of them, at least, is indispensable. Even if we grant that the instrumental errors are in all cases perfectly known for every observation, we still do not know either the names or the assumed right ascensions of the stars used in determining clock errors. Hence we cannot use the results, because the right ascensions given in standard catalogues not unfrequently differ by a second of space.

The declinations of the planet are sometimes determined by comparison with standard stars, sometimes by measures of nadir distance, combined with the latitude of the observatory. The Paris observations are reduced by the former method; those of most other observatories, by the latter. Using the latter method, it would naturally be supposed that the declinations from the observations of all observatories of which the latitudes are well determined ought to agree. But such is far from being the case. Compare, for instance, the declinations of fundamental stars concluded from observations with the great transit circle at Greenwich with those in the Tabulæ Reductionum of Wolfers, and we shall find that for stars more than 45° from the pole, the Greenwich positions are systematically nearly a second south of Wolfers', an amount greater than the probable error of a single isolated observation. We cannot impeach either authority. Wolfers' positions depend on such authorities as Pond, Struve, Argelander, Henderson, Airy, and Bessel. The conscientious care bestowed on the reduction of the Greenwich observations would seem to render their results unimpeachable. Besides, from a comparison of Winnecke's observations of his "Mars Stars" in

1862 with those of Greenwich, it would seem that the meridian circle of Pulkowa gives declinations an entire second farther south than those of the great transit circle; so that had the Pulkowa instrument been employed on fundamental stars, their declinations would have been 2″ less than Wolfers'. On the other hand, the Cambridge (Eng.) mural circle places the fundamental stars even farther north than Wolfers, and the Washington mural nearly as far north.

It is foreign to our present purpose to speculate upon the causes of these discrepancies; we are concerned only with their existence and amount. Their existence renders it absolutely necessary to correct the declinations as well as the right ascensions in order to reduce them to a common standard; and no observations have been used unless data for these corrections could be obtained.

This rule necessitates the entire rejection of nearly all the vast mass of observations on which Walker's theory was founded. In the case of the micrometric comparisons, no sufficient data seem to exist for determining the positions of the comparison stars; the results are, therefore, heterogeneous in their character. However valuable they might have been when made, it will not be admissible to combine them with the fifteen years of meridian observations made since. Micrometric observations were almost given up after 1850, and the planet was left to be followed by the meridian instruments of the larger observatories. The superior accuracy of this class of observations may be inferred from the fact that the comparatively small error in Walker's radius vector is made evident by them even during the period of construction of Walker's theory.

A similar remark applies to the meridian observations. Four years of observations made at a great number of observatories may be indiscriminately combined on the supposition that the systematic as well as the accidental errors will destroy each other, particularly if each series extends through the entire period. But, as few or none of these series made at observatories able to publish any thing but their results are continued later than 1849, it will not do to assume that the mean of their systematic errors, as fixed by the standard we have assumed, would vanish.

The observations which fulfil the conditions we have indicated are made at observatories, as follows:

Ancient observations.

Paris, by Lalande, May 8 and 10 1795.

Modern observations.

Greenwich,	1846 to 1864.
Cambridge,	1846 to 1857.
Paris,	1856 to 1861.
Washington,	1846 to 1850.
Washington,	1861 to 1864.
Hamburg,	1846 to 1849.
Albany,	1861 to 1864.

§ 22. *Reduction of Lalande's two observations of Neptune, May* 8–10, 1795.

The first of these observations is found in the Comptes Rendus, tome 24, p. 667. The second is in the Histoire Céleste, p. 158, and is the eighth star of the first

column. They were made with the large mural quadrant of the observatory attached to the Military School. The Histoire Céleste does not seem to contain any definite information as to the observer or observers by whom the observations were made.

The stars of comparison which I shall select for the determination of the errors of the instrument and clock are the following:

May 8.

β Virginis,
δ Corvi,
q Virginis,
ψ Virginis,
α Virginis,
h Virginis,
κ Virginis,
λ Virginis,
2 Libræ,
ε Libræ.

May 10.

α Virginis,
i Virginis,
λ Virginis,
2 Libræ,
μ Libræ,
ξ' Libræ.

These lists, I believe, include all of Bradley's stars observed by Lalande on the dates in question within the zone of the planet, for which reliable modern positions can readily be obtained. Their positions for the year 1795 were obtained as follows. The positions given by Bessel in the Fundamenta Astronomiæ were reduced by the precessions there given to the mean equinox and equator of 1795.0. The modern positions were obtained from the Greenwich Twelve Year Catalogue, the Greenwich observations, or Rumker's Catalogue, and were also reduced to 1795.0 with Bessel's precessions. The difference of the results, being supposed due to proper motion, was divided proportionally to the time, and the concluded true position for 1795 obtained. As Lalande's observations are subject to errors of several seconds, any farther refinement in investigating the positions of the stars would be a waste of labor. In the following table is exhibited the position of the star at the two epochs, referred to the mean equinox and equator of 1795.0, with the modern authorities, and the concluded mean positions for 1795.0:

Star.	R. A., 1755.	Seconds of R. A., modern epoch.	Year of modern epoch.	Modern authority.	Dec. 1755.	Seconds of modern Dec.	For 1795.0. Concluded. R. A.	Dec.
	h. m. s.	s.			° ′ ″	″	h. m. s.	′ ″
δ Corvi,	12 19 16.36	15.87	1850	12 Y. C.	— 15 22 13.2	28.7	12 19 16.15	— 15 22 19.7
q Virginis,	12 23 12.94	12.50	1840	12 Y. C.	— 8 19 9.8	9.7	12 23 12.73	— 8 19 9.8
ψ Virginis,	12 43 42.28	42.40	1840	12 Y. C.	— 8 25 17.5	21.9	12 43 42.34	— 8 25 19.5
i Virginis,	13 15 54.88	54.32	1859	Gr. Obs. 1859	— 11 38 6.2	10.0	13 15 54.66	— 11 38 7.7
h Virginis,	13 22 11.38	11.30	1845	12 Y. C.	— 9 6 11.5	15.1	13 22 11.34	— 9 6 13.1
κ Virginis,	14 1 58.50	58.85	1840	12 Y. C.	— 9 18 39.3	37.3	14 1 58.67	— 9 18 38.4
λ Virginis,	14 8 2.29	2.41	1840	12 Y. C.	— 12 25 11.2	9.7	14 8 2.35	— 12 25 10.5
2 Libræ,	14 12 25.07	25.17	1842	Rumker.	— 10 46 5.9	11.7	14 12 25.12	— 10 46 8.6
μ Libræ,	14 38 6.33	6.19	1845	12 Y. C.	— 13 17 6.0	8.4	14 38 6.27	— 13 17 7.1
ξ' Libræ,	14 43 16.60	16.11	1842	Rumker.	— 11 3 6.2	6.3	14 43 16.37	— 11 3 6.2
ε Libræ,	15 13 6.60	6.14	1842	Rumker.	— 9 34 22.7	57.6	15 13 6.39	— 9 34 29.5

The above places were reduced to the dates of observation with the constants of the Tabulæ Regiomontanæ.

The apparent positions of β Virginis and α Virginis are derived from the same work, correcting the Declination of the latter by $+0''.60$. The former is not used for index error, owing to its distance from the zone of Neptune.

Intervals of wires.

On attempting to test the wire intervals of Lalande, H. C., p. 576, the interval of the third wire was found to exhibit well-marked systematic discrepancies. The observations of May 10 concur very well in indicating a diminution of $0^s.10$; and this correction has been applied to Lalande's intervals. The interval for wire 1 has not been changed.

Deviation of instrument.

The next quantity required is the deviation of the instrument from the circle of Right ascension of the planet. On using Lalande's value of this correction, stars of different altitudes, even in the zone of observation, gave inadmissible discrepancies. It is found necessary to reduce the value to less than half. This will be readily seen from the table below.

Clock error, &c.

The following tables give, for each star and each date—

The number of wires observed, $\frac{1}{2}$ meaning a doubtful observation.

The concluded time of transit over the middle wire.

Lalande's correction to this time for deviation of the middle wire, this deviation being supposed to vanish at the circle reading for Neptune, viz.: 60° 7′.

The correction for deviation actually applied, derived from the comparison of clock corrections given by β Virginis and δ Corvi.

Seconds of apparent R. A. of star.

The clock correction, using Lalande's deviation.

The clock correction, using the concluded deviation.

The weight assigned to the result for clock correction, depending on the number of wires, and the proximity of the star to the planet.

For the second observation the deviation is of less importance than for the first, the planet being near the middle of the zone, and the mean of the corrections, therefore, very small.

1795, May 8.								
Name of star.	N.	T.	D′.	D.	R. A.	C′.	C.	W.
		h. m. s.	s.	s.	s.	s.	s.	
β Virginis,	1½	11 39 42.67	−3.80	−1.90	1.86	22.99	21.09	0
δ Corvi,	2	12 18 55.85	+0.81	+0.40	17.31	20.65	21.06	1
q Virginis,	2	12 22 52.10	−0.60	−0.30	13.84	22.34	22.04	2
ψ Virginis,	1	12 43 22.00	−0.58	−0.29	43.53	22.11	21.82	1
α Virginis,	3	13 14 4.23	−0.24	−0.12	26.09	22.10	21.98	4
h Virginis,	2	13 21 50.55	−0.44	−0.22	12.67	22.56	22.34	3
κ Virginis,	3	14 1 38.57	−0.40	−0.20	0.09	21.92	21.72	6
λ Virginis,	3	14 7 41.80	+0.20	+0.10	3.81	21.81	21.91	6
2 Libræ,	2	14 12 4.45	−0.11	−0.05	26.53	22.19	22.13	5
ε Libræ,	1½	15 12 46.07	−0.34	−0.17	7.89	22.16	21.99	2
May 10.								
α Virginis,	2	13 14 3.55	−0.24	−0.12	26.09	22.78	22.66	1
i Virginis,	2	13 15 32.90	+0.06	+0.03	55.99	23.03	23.06	1
λ Virginis,	2	14 7 41.20	+0.22	+0.11	3.82	22.40	22.51	2
2 Libræ,	2	14 12 3.40	−0.11	−0.06	26.53	23.24	23.19	2
μ Libræ,	1	14 37 45.10	+0.39	+0.20	7.79	22.30	22.49	1
ξ′ Libræ,	2	14 42 54.95	−0.06	−0.03	17.88	22.99	22.96	1

We have then

	May 8.	May 10.
Clock time of transit of planet,	14 11 36 .50	14 11 23 .50
Correction for clock and instrument,	+ 21 .94	+ 22 .82
Concluded apparent Right Ascension,	14 11 58 .44	14 11 46 .32
or,	212° 59′ 36″.6	212° 56′ 34″.8

Declinations.

We use Bessel's refractions. For the height of the Barometer, and the temperature of the air, we have:

			in.	°	
May 8,	. . . .	Bar. = 28 pou. 6 l.	= 30.37 Eng.;	T = 13 Reau.	= 61.2 Fah.
May 10.	Beginning of observations, .	Bar. = 28 pou. 3.1 l.	= 30.12 Eng.;	T = 13.7 Reau.	= 62.8 Fah.
	End " .	Bar. = 28 pou. 1.5 l.	= 30.07 Eng.;	T = 13 Reau.	= 61.2 Fah.

The equatorial points on the circle are concluded as follows:

May 8.					May 10.				
Name of star.	Observed Z. Dist.	Refraction.	Declination.	Equatorial point.	Name of star.	Observed Z. Dist.	Refraction.	Declination.	Equatorial point.
	° ′ ″	′ ″		48° 49′ ″		° ″	′ ″	° ′ ″	48° 49′ ″
δ Corvi,	64 9 52	1 57.3	−15 22 29.0	20.3	α Virginis,	58 53 2	1 34.2	−10 5 17.3	18.9
q Virginis,	57 7 11	1 28.0	−8 19 17.5	21.5	i Virginis,	60 25 54	1 40.2	−11 38 14.2	20.0
ψ Virginis,	57 13 17	1 28.4	−8 25 26.6	18.8	λ Virginis,	61 12 50	1 43.5	−12 25 15.4	18.1
α Virginis,	58 53 0	1 34.3	−10 5 17.3	17.0	2 Libræ,	59 33 59	1 36.8	−10 46 13.3	22.5
h Virginis,	57 54 5	1 30.6	−9 6 19.0	16.6	μ Libræ,	62 4 43	1 47.3	−13 17 10.7	19.6
κ Virginis,	58 6 37	1 31.4	−9 18 43.0	25.4	ξ′ Libræ,	59 50 50	1 37.9	−11 3 9.5	18.4
λ Virginis,	61 12 43	1 43.5	−12 25 15.2	11.3					
2 Libræ,	59 33 57	1 36.9	−10 46 13.1	20.8					
ε Libræ,	58 22 13	1 32.4	−9 34 31.7	13.7					

Taking the means of the separate results for equatorial point, we have, for the apparent declinations of Neptune—

	May 8.	May 10.
	° ′ ″	° ′ ″
Observed circle reading,	60 8 17	60 7 19
Refraction,	1 39.0	1 39.0
Corrected circle reading,	60 9 56.0	60 8 58.0
Equatorial point,	48 49 18.4	48 49 19.6
Apparent declination,	—11 20 37.6	—11 19 38.4

§ 23. Probable errors of these positions.

So far as we can judge from the discordance of the clock errors, and equatorial points derived from the several stars, the probable error of a single observation over a single wire in right ascension would appear to be about $0^s.27$, and the probable error of a single observed zenith distance about $2''.2$. The agreement of the difference of the two observations with the computed motion of the planet shows that neither observation is affected with any abnormal error. We conclude, therefore, that the probable error of the normal place derived from the two observations is about $2''.8$ in R. A. and $1''.5$ in declination.

Notwithstanding the magnitude of these probable errors, the observations will be very valuable during the remainder of the present century, owing to the weight with which they enter into the expressions of the elements. But in the twentieth century the observations made after 1846 will enable astronomers to compute the position of the planet in 1795 with a much higher degree of accuracy than Lalande could observe it.

A similar remark applies to Lamont's accidental zone observations in 1845. Valuable during the first two or three years, they afterward ceased to be so, because the theory soon became more accurate than the observation for an epoch so near the time of optical discovery. Had they been made in 1820, they would still have been valuable.

Reduction of the modern observations.

§ 24. The modern observations will be treated in the following manner. The observations of each year will be divided into four groups, according to the time of culmination of the planet. The first group will include all observations made after

	h. m. h. m.
	13 30 m. t.
Second, between	10 30 and 13 30.
Third, "	7 30 and 10 30.
Fourth, all made before	7 30.

The mean correction derived from each group will at first be regarded as the true correction applicable to the mean of the times of observation. This involves the supposition that the error of the ephemeris is changing uniformly during each series of observations. If we could compare with an ephemeris of the heliocentric

place of the planet, this hypothesis would be sufficiently near the truth for an entire year or more. But the error of geocentric place would be subject to an annual period though the errors of the heliocentric place should be invariable. Let us estimate the error of the hypothesis in question. Put

r = radius vector of Neptune.
D = difference of longitude of Sun and Neptune.
δv, δr, errors of heliocentric longitude and radius vector.

Then the errors of geocentric longitude will be, approximately,

$$\delta v\left(1+\frac{\cos D}{r}\right)+\frac{\delta r}{r^2}\sin D.$$

Of this expression the part

$$\frac{\delta v}{r}\cos D+\frac{\delta r}{r^2}\sin D$$

will not be regularly progressive, but will change with the sine and cosine of D, the period of which is about 368 days.

The integral of this expression gives for the mean value of the error, while D is increasing from D_0 to D_1,

$$\frac{\delta v}{r}\cdot\frac{\sin D_1-\sin D_0}{D_1-D_0}-\frac{\delta r}{r^2}\cdot\frac{\cos D_1-\cos D_0}{D_1-D_0}.$$

By putting

$$D=\frac{D_1-D_0}{2},\qquad \delta=D_1-D=D-D_0,$$

and developing according to powers of δ, this expression becomes

$$\frac{\delta v}{r}\cos D\left(1-\frac{\delta^2}{6}\right)+\frac{\delta r}{r^2}\sin D\left(1-\frac{\delta^2}{6}\right).$$

This, plus the error of heliocentric longitude, is the mean error which will be given by a series of observations equally scattered through a period $\pm\delta$ on each side of the mean epoch D. But what we really want is the error at the mean epoch itself; that is,

$$\delta v+\frac{\delta v}{r}\cos D+\frac{\delta r}{r^2}\sin D;$$

so that we must correct the mean error actually found by the quantity

$$\frac{\delta^2}{6}\left(\frac{\delta v}{r}\cos D+\frac{\delta r}{r^2}\sin D\right),$$

or, since δ is generally about $1^h_{\frac{1}{4}}$, and r about 30,

$$.027\left(\frac{\delta v}{30}\cos D+\frac{\delta r}{900}\sin D\right)$$

The maximum value of δv being less than 30″, the first term will be entirely neglected. The value of δr sometimes amounts to .018, so that the correction arising from the second term may sometimes amount to 0″.11. We shall, therefore, take account of it in a few cases.

The ephemeris which will be compared with observation in order to deduce normal places of the planet will be the same with which the Greenwich observations are compared, namely, Walker's ephemeris until the year 1854, and Kowalski's ephemeris in subsequent years. It will be remembered, however, that these ephemerides are used only for the purpose of obtaining normal places, and in order to save the trouble of comparing every individual observation with the provisional theory.

§ 25. *Mean corrections of the Ephemeris of Neptune given by observations at the different observatories, without correction for systematic differences.*

Greenwich.

Date.	R. A.	Dec.	No.
	s	″	
1846, Oct. 14,	−0.050	+0.48	12
Nov. 16,	−.070	+0.55	7
1847, July 26,	−.150	+2.05	4
Aug. 20,	−.097	+2.23	10
Oct. 3,	−.145	+1.43	10
Nov. 24,	−.056	+1.76	8
1848, July 28,	−.062	+1.16	4
Aug. 31,	+.002	−0.20	8
Oct. 7,	−.104	+0.01	14
Nov. 16,	+.022	+0.11	4
1849, Sept. 3,	−.027	+0.65	6
Oct. 17,	+.080	+1.70	8
Nov. 28,	−.060	+1.96	5
1850, Aug. 27,	−.079	−1.00	13
Oct. 16,	+.040	+0.20	13
Nov. 24,	+.020	−0.52	16
1851, Sept. 1,	−.162	−1.07	16
Oct. 12,	+.060	−0.97	4
Nov. 9,	−.040	−1.94	5
1852, Aug. 7,	−.260	−2.34	5
Sept. 11,	−.160	−2.44	10
Oct. 12,	−.140	−3.36	10
Nov. 22,	−.080	−2.27	5
1853, Sept. 1,	−.256	−2.59	14
Oct. 11,	−.177	−2.93	16
Nov. 19,	−.160	−2.71	3
1854, Aug. 30,	−.420	−3.60	13
Sept. 24,	−.370	−3.94	11
Oct. 27,	−.310	−3.68	7
Dec. 5,	−.300	−4.36	4
1855, Aug. 10,	−.189	−0.84	7
Sept. 8,	−.046	−0.06	16
Oct. 22,	+.183	+0.80	6
Nov. 29,	+.177	+1.51	6
1856, Aug. 8,	−.220	−1.06	10
Sept. 13,	−.080	−1.06	7
Oct. 26,	+.076	+1.41	9
Nov. 17,	+.123	+1.67	6
1857, Aug. 14,	−.356	−2.43	5
Sept. 22,	−.130	−0.50	12
Oct. 24,	+.030	+0.29	5
Dec. 5,	+.130	+0.16	10
1858, Aug. 18,	−.391	−1.74	14
Sept. 24,	−.260	−1.81	13
Oct. 25,	−.206	−1.00	16
Dec. 10,	−.058	−0.76	11
1859, Aug. 19,	−.500	−3.27	9
Sept. 28,	−.446	−3.11	17
Nov. 3,	−.315	−2.56	15
Dec. 16,	−.328	−1.46	10

Cambridge.

Date.	R. A.	No.	Dec.	No.
	s		″	
1846, Oct. 13,	−0.014	10	+1.51	8
Nov. 7,	.000	14	+1.43	15
1847, July 27,	−.062	5	+2.30	4
Aug. 22,	−.090	18	+2.25	17
Oct. 8,	−.100	14	+2.18	13
Nov. 20,	−.022	13	+0.66	14
1848, July 22,	−.056	8	+0.88	8
Aug. 27,	−.048	19	+1.85	19
Oct. 9,	−.018	16	+0.75	17
Nov. 19,	+.009	10	+1.05	11
1849, Aug. 21,	−.087	15	+0.72	18
Oct. 15,	−.038	16	−0.17	16
Nov. 22,	+.090	11	+0.21	2
1850, Aug. 29,	−.089	10	+0.48	11
Oct. 16,	+.011	14	−0.13	15
Nov. 23,	+.039	12	+0.14	13
1851, Sept. 4,	−.054	18	−1.62	19
Oct. 17,	+.028	11	−1.61	10
Nov. 28,	+.014	9	−1.91	10
1852, Aug. 29,	−.037	15	−1.53	15
Oct. 11,	−.048	10	−2.52	11
Dec. 4,	+.038	7	−2.99	7
1853, Sept. 2,	−.048	4	−2.48	5
Oct. 24,	−.134	13	−3.04	13
Nov. 27,	+.031	11	−2.53	12
1854, Sept. 4,	−.314	11	−3.59	12
Oct. 11,	−.273	15	−4.38	3
Nov. 24,	−.165	4	−5.17	8
	s		″	
1855, Sept. 8,	−0.046	12	+0.48	9
Oct. 12,			+0.50	6
Dec. 10,	+0.206	9	+3.07	7
1856, Sept. 12,	−0.099	9	+0.05	8
Oct. 29,	+0.120	8	+1.73	7
Nov. 28,	+0.164	5	+2.50	5
1857, Sept. 14,	−0.030	9	−0.83	12
Oct. 25,	+0.104	5	−0.34	5
Dec. 11,	+0.175	8	+0.16	9

GREENWICH (Cont.).

Date.	R. A.	Dec.	No.
	s	"	
1860, Aug. 20,	−0.760	−5.02	4
Sept. 20,	−0.685	−3.86	13
Oct. 31,	−0.662	−3.38	15
Dec. 13,	−0.630	−4.73	2
1861, Aug. 22,	−0.940	−5.41	4
Sept. 18,	−0.861	−5.62	16
Oct. 30,	−0.861	−5.18	12
Dec. 7,	−0.993	−5.14	7
1862, Aug. 24,	−1.12	−7.20	6
Sept. 25,	−1.162	−6.76	13
Nov. 4,	−1.139	−7.00	11
Dec. 17,	−1.18	−7.06	4
1863, Aug. 28,	−1.585	−9.91	2
Sept. 23,	−1.461	−8.62	9
Nov. 12,	−1.388	−8.33	4
Dec. 15,	−1.375	−8.41	2
1864, Oct. 3,	−1.680	−11.03	3
Nov. 8,	−1.639	−10.52	7

WASHINGTON (Walker's Eph.).

Date.	R. A.	No.	Dec.	No.
	s			
1846, Nov. 9,	+0.096	10	+2.16	7
1847, Aug. 23,	−0.205	15	+2.27	6
Oct. 14,	−0.023	9	+1.80	7
Nov. 8,	+0.052	5	+1.96	3
1848, Aug. 30,	−0.076	10	+0.80	14
Oct. 2,	−0.121	12	+1.71	10
1849, Sept. 11,	−0.154	5		
Oct. 12,	−0.014	8	+1.06	6
1850, Oct. 13,	−0.032	9	+0.94	25
Nov. 11,	−0.068	5	+1.25	13
1861, Oct. 29,	−1.695	6	−8.70	5
Dec. 16,	−1.593	11	−8.64	10
1862, Sept. 23,	−2.000	2		
Nov. 14,	−1.860	3	−9.85	2
Dec. 12,	−1.827	6	−10.9	1
1863, Oct. 13,	−2.22	3	−13.82	5
Nov. 12,	−2.19	3	−13.52	6
Dec. 8,	−2.054	5	−12.76	7
1864, Aug. 7,	−2.69	3	−15.5	4
Nov. 17,	−2.52	5	−14.6	12
Dec. 20,	−2.38	5	−14.0	2

ALBANY (Kowalski).

Date.	R. A.	No.	Dec.	No.
	s		"	
1861, Sept. 1,	−0.778	5	−6.02	5
Nov. 11,	−0.825	8	−5.42	8
Dec. 14,	−0.847	9	−5.44	9

PARIS (Walker).

Date.	R. A.	No.	Dec.	No.
	s		"	
1856, Sept. 14,	−0.669	12	−3.96	8
Oct. 25,	−0.606	14	−3.91	15
Dec. 21,	−0.470	2		
1857, Sept. 19,	−0.768	10	−4.98	10
Oct. 25,	−0.825	13	−5.95	12
Dec. 14,	−0.729	7	−6.13	7

PARIS (Kowalski).

Date.	R. A.	No.	Dec.	No.
	s		"	
1858, Sept. 21,	−0.291	18	−1.14	17
Oct. 27,	−0.235	19	−0.76	19
1859, Aug. 23,	−0.630	5	−2.64	5
Sept. 23,	−0.474	9	−2.50	8
Nov. 17,	−0.337	11	−1.92	14
Dec. 7,	−0.430	2	−2.20	2
1860, Sept. 29,	−0.608	6	−3.75	6
Oct. 31,	−0.618	12	−3.51	10
1861, Sept. 28,	−0.960	7	−5.56	7
Nov. 4,	−0.948	17	−5.52	17
Dec. 9,	−0.890	5	−5.60	4

HAMBURG.

Date.	R. A.	Dec.	No.
	s	"	
1846, Oct. 7,	−0.098	−1.43	9
Nov. 21,	−0.131	+0.10	16
1847, Aug. 22,	−0.061	−1.43	17
Oct. 10,	−0.102	+0.10	22
Nov. 26,	−0.051	+0.32	12
1848, July 20,	0.000	−0.20	7
Aug. 27,	−0.118	−2.17	15
Oct. 4,	−0.043	−2.15	12
1849, Sept. 3,	−0.014	−0.92	9
Oct. 10,	−0.008	−0.50	16
Nov. 25,	+0.071	−0.71	10

ALBANY (Walker).

Date.	R. A.	No.	Dec.	No.
	s		"	
1862, Aug. 25,	−1.927	3	−13.05	4
Sept. 21,	−1.905	14	−13.67	17
Oct. 31,	−1.815	9	−13.46	10
Dec. 17,	−1.732	6	−12.73	6
1863, Sept. 27,	−2.228	12	−14.96	1
Nov. 6,	−2.145	10	−15.38	9
Dec. 14,	−2.053	6	−14.80	6
1864, Sept. 29,	−2.490	6	−17.70	6
Nov. 9,	−2.437	9	−16.29	9
Dec. 14,	−2.360	3	−16.27	3

§ 26. *Corrections to the observed positions in order to render them strictly comparable with each other.*

These corrections have been derived from a comparison of the positions of the ten fundamental clock stars, from γ Aquilæ to α Ceti inclusive, given by observations at the different observatories, with the adopted standard positions. The standard right ascensions are those of Dr. Gould, prepared for the United States Coast Survey. The declinations are those of Wolfers in the "Tabulæ Reductionum," diminished by 0″.50. Both are given in the following table:

	R. A. 1850.0.	Annual var. 1850.	Dec. 1850.0.	Annual var. 1850.	Cor. to Am. Eph. R. A.	Cor. to Am. Eph. Dec.
	h. m. s.	s.	° ′ ″	″		
γ Aquilæ,	19 39 7.68	+2.853	+10 15 5.02	+8.41	+2	−2
α Aquilæ,	19 43 27.82	2.928	+8 28 33.45	9.13	−1	+5
β Aquilæ,	19 47 56.67	2.948	+6 2 8.68	8.62	+3	+5
α^2 Capricorni,	20 9 43.69	3.335	−13 0 20.90	10.77	+2	+13
α Aquarii,	21 58 4.68	3.084	−1 2 47.41	17.28	+4	+8
α Pegasi,	22 57 17.50	2.983	+14 23 57.36	19.30	0	+1
α Andromedæ,	0 0 38.57	3.085	+28 15 43.72	19.91	+2	0
γ Pegasi,	0 5 30.99	3.081	+14 20 57.67	20.04	+2	+1
α Arietis,	1 58 43.64	3.364	+22 44 1.97	17.29	+1	0
α Ceti,	2 54 26.58	+3.130	+3 29 52.45	+14.42	+6	+5

In reducing the Albany observations, it was found advisable to add ω Piscium to the number of standard stars for determining these corrections. Its assumed position is

R. A. 1860.0.	Declination 1860.0.
23 51 7.42	+6° 5′ 17″.9

The observed mean right ascensions and declinations of these stars, reduced to the beginnings of the several years, have been compared with those derived from the above table, giving the result from each star a weight proportional to the number of observations when the observations were few in number, but giving each result equal weight when they were numerous. Thus the following systematic corrections have been derived:

Greenwich.	R. A.	Dec.
	s	″
1846	+0.044	−0.04
47	+0.059	−0.19
48		+0.08
49		−1.51
50		−0.52
51	−0.020	−0.22
52		+0.21
54		+0.18
55		+0.05
56	−0.038	+0.30
58	−0.015	+0.48
60	−0.005	
61	−0.003	+0.24
62		+0.63
63		+0.27
6 Y. Cat. of 1854	−0.020	
7 Y. Cat. of 1860	+0.002	

Cambridge.	R. A.	Dec.
	s	″
1846		−1.21
47		−0.99
48		−0.25
49		−0.05
50	−0.038	−0.80
51	−0.052	−1.17
52		−0.20
53		−0.75
54	−0.044	−0.73
57	−0.052	

Paris.	R. A.	Dec.
	s	″
1856	+0.020	−0.57
58	+0.021	−0.23
60	+0.023	−0.53

Washington.	R. A.	Dec.
	s	″
1846	+0.034	−0.34
47	+0.057	−0.41
48	+0.036	−0.57
49, 50	+0.039	−1.04
61	+0.058	−0.89
63		−0.69
64		−1.37

Albany.	R. A.	Dec.
	s	″
1861	+0.006	+0.17
62	000	0.00
63	000	+0.78
64	000	+0.97

REMARKS ON THE PRECEDING CORRECTIONS.

Greenwich.

The corrections actually applied to the right ascensions from 1848 to 1853 have been derived by comparing the corrections on p. IV. of the introduction to the Greenwich six-year catalogue for 1854 with the corrections given by that catalogue, namely, — $0^s.020$. From 1857 to 1864 the corrections have been derived in the same way from the seven-year catalogue for 1860. The entire list of corrections is as follows:

1846,	+ $0^s.044$
47,	+ 0 .059
48,	+ 0 .052
49–55,	— 0 .010
56,	— 0 .025
57–61,	— 0 .008
62–64,	+ 0 .002

The corrections to the declination have been concluded from year to year from the table.

Cambridge.

One consistent set of adopted right ascensions having been used in the reductions of the Cambridge observations, the constant correction

$$— 0^s.046$$

has been applied to the right ascensions throughout. The declinations have been corrected as follows:

1846–47,	— $1''.12$
1848–57,	— 0 .58

Washington.

The corrections to the Washington right ascensions from 1846 to 1850 have been derived from a general comparison of twenty-five fundamental stars near the equator with the results of the Greenwich observations. The mean + $0^s.042$ has been adopted as the constant correction for those years. After 1861, no correction is needed, Dr. Gould's Right ascensions having been adopted in the reductions.

The corrections to the declinations for 1861 have been derived from those for 1862. The latter were diminished by $0''.20$ for error of nadir point, while no such correction was applied to the former.

Hamburg.

Having applied to Charles Rumker, Esq., M.A., of the observatory at Hamburg, for information respecting the data used in the reduction of the Hamburg observations of Neptune, I was informed that both right ascensions and declinations

depended on the positions of the Nautical Almanac stars. For the years 1846–47, the Nautical Almanac right ascensions require the constant correction $-0^s.003$, and in 1848–49 the correction $+0^s.049$, to reduce them to those adopted.

The declinations do not seem so easily reducible to our adopted standard. They are, therefore, not included.

All the Washington, and some of the Paris and Albany, observations having been compared with Walker's Ephemeris in years subsequent to 1855, the following corrections have been applied for differences of Ephemerides:

To Paris Corrections.

Date.	R. A.	Dec.
	s	
1856, Sept. 14,	+ 0.54	+ 4.68
Oct. 25,	+ 0.65	+ 5.75
1857, Sept. 19,	+ 0.676	+ 5.02
Oct. 25,	+ 0.80	+ 5.82
Dec. 14,	+ 0.80	+ 5.92

To Washington and Albany Corrections.

Date.	R. A.	Dec.
	s	
1861, Oct. 29,	+ 0.76	+ 5.5
Dec. 16,	+ 0.70	+ 4.9
1862, Aug. 25,	+ 0.90	+ 6.3
Sept. 21,	+ 0.85	+ 6.2
23,	+ 0.85	+ 6.2
Oct. 31,	+ 0.76	+ 5.4
Nov. 14,	+ 0.75	+ 5.0
Dec. 12,	+ 0.70	+ 5.1
17,	+ 0.70	+ 5.1
1863, Sept. 27,	+ 0.845	+ 5.9
Oct. 13,	+ 0.81	+ 5.6
Nov. 6,	+ 0.78	+ 5.3
12,	+ 0.77	+ 5.5
Dec. 8,	+ 0.73	+ 5.2
14,	+ 0.73	+ 5.2
1864, Aug. 7,	+ 0.91	+ 6.2
Sept. 29,	+ 0.87	+ 6.0
Nov. 9,	+ 0.90	+ 5.9
17,	+ 0.88	+ 5.5
Dec. 14,	+ 0.82	+ 5.8
20,	+ 0.82	+ 5.5

§ 27. The concluded corrections of the ephemeris for normal dates generally near the mean of the means have been concluded by applying to the corrections of pp. 51, 52 the following corrections:

1. Correction for systematic error given by fundamental stars.
2. Reduction, when the change of error was rapid, from the dates of the means to the dates of the normals.
3. $0.027 \frac{\delta r}{900} \sin D$ for second differences of error, when $\delta r > .01$.
4. Correction just given for difference of ephemerides.

The results are given in the following table. The small figures show the relative weights assigned to the separate results, which are, to a certain extent, a matter of judgment, but which are assigned without any reference to the magnitude of the correction itself.

Corrections to the Tabular Right Ascensions given by the different Observatories, with the Concluded Corrections and Concluded Normal Right Ascensions.

(The units are hundredths of seconds of time.)

	Gr.	Cam.	Par.	Wash.	Ham.	Concluded.	Tab. R. A.	R. A. from Observation.
							s.	h. m. s.
1846, Oct. 14,	-1_5	-6_2			-10_2	-4	55.02	21 51 54.98
Nov. 14,	-3_4	-5_3		$+14_5$	-13_2	$+1$	22.99	21 51 23.00
1847, July 26,	-9_3	-11_1				-9	1.94	22 8 1.85
Aug. 17,	-4_5	-14_3		-16_6	-6_2	-11	51.90	22 5 51.79
Oct. 8,	-9_5	-14_2		$+2_5$	-10_3	-6	3.42	22 1 3.36
Nov. 18,	0_4	-7_2		$+9_3$	-5_2	0	4.28	22 0 4.28
1848, July 25,	-1_3	-10_2			$+5_1$	-3	49.85	22 16 49.82
Aug. 29,	$+5_5$	-9_3		-3_6	-7_2	-2	21.55	22 13 21.53
Oct. 6,	-5_6	-6_2		-8_5	$+1_2$	-5	53.89	22 9 53.84
Nov. 17,	$+7_3$	-4_2				$+3$	38.40	22 8 38.43
1849, Sept. 1,	-4_3	-13_2		-12_3	$+3_2$	-7	51.43	22 21 51.36
Oct. 15,	$+7_4$	-8_2		$+3_6$	$+4_2$	$+2$	2.74	22 18 2.76
Nov. 25,	-7_3	$+4_2$		-2_1	$+12_2$	$+1$	19.06	22 17 19.07
1850, Aug. 28,	-9_5	-14_2				-10	62.59	22 31 2.49
Oct. 15,	$+3_5$	-4_2		$+1_6$		$+1$	43.45	22 26 43.46
Nov. 20,	$+1_6$	-1_2		-2_3		$+0$	42.94	22 25 42.94
1851, Sept. 2,	-17_6	-10_3				-15	15.94	22 39 15.79
Oct. 14,	$+5_3$	-2_2				$+2$	26.94	22 35 26.96
Nov. 20,	-5_3	-3_2				-4	11.92	22 34 11.88
1852, Aug. 7,	-27_3					-27	25.60	22 50 25.33
Sept. 5,	-17_5	-8_2				-15	34.10	22 47 33.95
Oct. 12,	-15_5	-9_2				-13	9.83	22 44 9.70
Nov. 28,	-9_3	-1_1				-7	44.70	22 42 44.63
1853, Sept. 1,	-26_6	-9_1				-24	40.14	22 56 39.90
Oct. 15,	-18_6	-18_4				-18	34.47	22 52 34.29
Nov. 24,	-17_2	-2_3				-8	7.41	22 51 7.33
1854, Aug. 30,	-43_5	-37_3				-41	32.47	23 5 32.06
Sept. 24,	-38_5					-38	1.25	23 3 0.87
Oct. 27,	-32_4	-33_6				-33	23.38	23 0 23.05
Dec. 5,	-31_3	-21_2				-27	40.04	22 59 39.77
1855, Aug. 10,	-20_{14}					-20	2.20	23 16 2.00
Sept. 8,	-6_{24}	-10_6				-7	16.50	23 13 16.43
Oct. 22,	$+17_{12}$					$+17$	15.60	23 9 15.77
Nov. 29,	$+17_{12}$	$+15_5$				$+16$	57.33	23 7 57.49

Corrections to the Tabular Right Ascensions given by the different Observatories, with the Concluded Corrections and Concluded Normal Right Ascensions (Cont.).

(The units are hundredths of seconds of time.)

	Gr.	Cam.	Par.	Wash.	Albany.	Concluded.	Tab. R. A.	R. A. from Observation.
							s.	h. m. s.
1856, Aug. 8,	-25_{20}					-25	41.68	23 24 41.43
Sept. 13,	-11_{14}	-14_{5}	-15_{3}			-12	17.95	23 21 17.83
Oct. 26,	$+5_{18}$	$+7_{5}$	$+6_{3}$			$+6$	28.76	23 17 28.82
Nov. 17,	$+11_{12}$	$+11_{3}$				$+11$	28.90	23 16 29.01
1857, Aug. 13,	-37_{12}					-37	50.90	23 32 50.53
Sept. 21,	-14_{24}	-5_{6}	-6_{2}			-12	6.08	23 29 5.96
Oct. 24,	$+2_{12}$	$+6_{3}$	0_{3}			$+2$	8.91	23 26 8.93
Dec. 8,	$+11_{21}$	$+13_{5}$	$+9_{2}$			$+11$	45.10	23 24 45.21
1858, Aug. 18,	-40_{28}					-40	58.46	23 40 58.06
Sept. 23,	-27_{26}		-27_{5}			-27	29.38	23 27 29.11
Oct. 28,	-20_{32}		-21_{4}			-20	22.93	23 34 22.73
Dec. 12,	-6_{22}					-6	6.89	23 33 6.83
1859, Aug. 21,	-51_{20}		-61_{1}			-52	14.82	23 49 14.30
Sept. 23,	-46_{30}		-45_{2}			-46	3.51	23 46 3.05
Nov. 8,	-32_{25}		-32_{3}			-32	9.94	23 42 9.62
Dec. 14,	-33_{20}		-41_{1}			-33	25.27	23 41 24.94
1860, Aug. 20,	-77_{10}					-77	45.29	23 57 44.52
Sept. 23,	-69_{25}		-59_{2}			-68	30.53	23 54 29.85
Oct. 31,	-67_{25}		-60_{3}			-66	3.89	23 51 3.23
Dec. 13,	-63_{5}					-63	40.91	23 49 40.28
1861, Aug. 22,	-95_{10}					-95	4.99	0 6 4.04
Sept. 18,	-87_{30}		-94_{2}		-77_{8}	-86	33.38	0 3 32.52
Oct. 30,	-87_{20}		-93_{5}	-88_{18}	-82_{8}	-88	36.27	23 59 35.39
Dec. 7,	-100_{15}		-87_{2}	-84_{33}	-84_{9}	-89	56.66	23 57 55.77
1862, Aug. 24,	-112_{15}				-103_{7}	-109	24.31	0 14 23.22
Sept. 23,	-116_{25}			-115_{6}	-105_{15}	-113	34.92	0 11 33.79
Nov. 6,	-114_{20}			-111_{18}	-105_{10}	-112	33.12	0 7 32.00
Dec. 15,	-118_{10}			-113_{15}	-103_{8}	-112	12.76	0 6 11.64
1863, Aug. 28,	-159_{5}					-159	34.01	0 22 32.42
Sept. 27,	-146_{20}			-141_{8}	-138_{10}	-144	42.64	0 19 41.20
Nov. 17,	-138_{10}			-141_{8}	-136_{8}	-140	17.57	0 25 16.17
Dec. 12,	-137_{5}			-132_{12}	-132_{8}	-133	29.48	0 14 28.15
1864, Aug. 7,				-178_{7}		-178	22.99	0 32 21.21
Oct. 1,	-168_{8}				-162_{8}	-167	44.63	0 27 42.96
Nov. 12,	-163_{15}			-164_{15}	-154_{9}	-162	58.31	0 23 56.69
Dec. 17,				-156_{15}	-154_{6}	-157	45.62	0 22 44.05

Correction to the Declinations, with the Concluded Declinations.

	Gr.	Cam.	Par.	Wash.	Albany.	Concluded.	Tab. Dec.	Concluded Dec. from Obs.
	″						″	° ′ ″
1846, Oct. 14,	$+0.4_4$	$+0.4_2$				$+0.4$	20.6	−13 31 20.2
Nov. 14,	$+0.5_3$	$+0.3_3$		$+1.8_3$		$+0.9$	54.7	13 33 53.8
1847, July 26,	$+1.9_2$	$+1.2_1$				$+1.7$	31.0	−12 8 29.3
Aug. 17,	$+2.0_4$	$+1.1_3$		$+1.8_3$		$+1.7$	48.0	12 20 46.3
Oct. 8,	$+1.2_4$	$+1.1_2$		$+1.4_3$		$+1.2$	6.2	12 47 5.0
Nov. 18,	$+1.6_3$	-0.5_3		$+1.5_1$		$+0.7$	2.6	12 52 1.9
1848, July 25,	$+1.2_2$	$+0.3_2$				$+0.8$	39.6	−11 23 38.8
Aug. 29,	$+0.1_3$	$+1.3_3$		$+0.2_4$		$+0.5$	44.9	11 43 44.4
Oct. 6,	$+0.1_5$	$+0.2_3$		$+1.1_4$		$+0.5$	3.1	12 3 2.6
Nov. 17,	$+0.2_2$	$+0.5_2$				$+0.4$	32.9	12 9 32.5
1849, Sept. 1,	-0.9_3	$+0.1_3$				-0.4	55.1	−10 59 55.5
Oct. 15,	$+0.2_3$	-0.8_3		$+0.0_3$		-0.2	33.0	11 21 33.2
Nov. 25,	$+1.4_2$	-0.4_3				$+0.3$	5.2	11 25 4.9
1850, Aug. 28,	-1.5_5	-0.1_2				-1.1	52.6	−10 10 53.7
Oct. 15,	-0.3_5	-0.7_3		-0.1_5		-0.3	59.4	10 35 59.7
Nov. 20,	-1.0_6	-0.4_3		$+0.2_4$		-0.5	15.3	10 41 15.8
1851, Sept. 2,	-1.3_6	-2.2_3				-1.6	27.6	− 9 26 29.2
Oct. 14,	-1.2_2	-2.2_2				-1.7	3.1	9 49 4.8
Nov. 20,	-2.2_2	-2.5_2				-2.4	45.9	9 55 48.3
1852, Aug. 7,	-2.1_3					-2.1	44.2	− 8 22 46.3
Sept. 5,	-2.2_4	-2.1_3				-2.2	37.0	8 40 39.2
Oct. 12,	-3.1_4	-3.1_2				-3.1	5.7	9 1 8.8
Nov. 28,	-2.1_5	-3.6_2				-2.7	42.2	9 8 44.9
1853, Sept. 1,	-2.4_5	-3.1_1				-2.5	53.0	− 7 48 55.5
Oct. 15,	-2.7_5	-3.6_3				-3.1	58.4	8 14 1.5
Nov. 24,	-2.5_1	-3.1_3				-2.9	58.5	8 22 1.4
1854, Aug. 30,	-3.4_4	-4.2_3				-3.7	39.1	− 6 57 42.8
Sept. 24,	-3.8_4					-3.8	32.9	7 13 36.7
Oct. 27,	-3.5_3	-5.1_1				-3.9	30.6	7 29 34.5
Dec. 5,	-4.1_2	-5.7_2				-4.9	58.1	7 33 3.0
1855, Aug. 10,	-0.8_3					-0.8	54.9	− 5 54 55.7
Sept. 8,	0.0_5	-0.1_2				0.0	59.8	6 12 59.8
Oct. 22,	$+0.9_3$	$+0.2_1$				$+0.7$	4.1	6 38 3.4
Nov. 29,	$+1.6_3$	$+2.5_2$				$+2.0$	15.2	− 6 45 13.2

CORRECTION TO THE DECLINATIONS, WITH THE CONCLUDED DECLINATIONS (Cont.).

	Gr.	Cam.	Par.	Wash.	Albany.	Concluded.	Tab. Dec.	Concluded Dec. from Obs.
	″						″	° ′ ″
1856, Aug. 8,	-0.8_4					−0.8	21.4	−5 3 22.2
Sept. 13,	-0.7_3	-0.5_2	$+0.1_2$			−0.4	48.3	5 25 48.7
Oct. 26,	$+1.7_4$	$+1.1_2$	$+1.3_3$			+1.4	45.4	5 49 44.0
Nov. 17,	$+2.0_3$	$+1.7_1$				+1.9	29.2	5 55 27.3
1857, Aug. 13,	-2.0_2					−2.0	40.8	−4 14 42.8
Sept. 21,	-0.1_6	-1.3_3	-0.4_2			−0.5	29.9	4 39 30.4
Oct. 24,	$+0.7_2$	-0.9_1	-0.5_3			−0.2	6.4	4 58 6.6
Dec. 8,	$+0.6_4$	-0.4_2	-0.6_2			0.0	39.0	5 5 39.0
1858, Aug. 18,	-1.3_5					−1.3	44.6	−3 25 45.9
Sept. 23,	-1.3_4		-1.4_3			−1.3	55.2	3 48 56.5
Oct. 28,	-0.6_5		-1.0_3			−0.8	34.7	4 8 35.5
Dec. 12,	-0.3_5					−0.3	14.2	4 15 14.5
1859, Aug. 21,	-2.9_4		-3.0_2			−2.9	26.2	−2 35 29.1
Sept. 23,	-2.7_5		-2.9_3			−2.8	45.6	2 56 48.4
Nov. 8,	-2.1_5		-2.3_3			−2.2	19.5	3 21 21.7
Dec. 14,	-1.0_4		-2.6_2			−1.5	48.4	3 24 49.9
1860, Aug. 20,	-4.7_2					−4.7	13.8	−1 43 18.5
Sept. 23,	-3.6_5		-4.2_2			−3.8	3.1	2 5 6.9
Oct. 31,	-3.1_5		-4.0_3			−3.4	0.3	2 27 3.7
Dec. 13,	-4.4_1					−4.4	24.1	2 34 28.5
1861, Aug. 22,	-5.2_2					−5.2	4.6	−0 52 9.8
Sept. 18,	-5.4_5		-6.1_2		-5.8_2	−5.6	10.8	1 9 16.4
Oct. 30,	-4.9_4		-6.1_3	-4.1_2	-5.3_2	−5.1	35.1	1 34 40.2
Dec. 7,	-4.9_3		-6.1_2	-4.6_2	-5.3_2	−5.2	59.8	−1 44 5.0
1862, Aug. 24,	-6.6_3					−6.6	53.0	−0 0 59.6
Sept. 23,	-6.1_5				-7.5_0	−6.1	56.3	0 20 2.4
Nov. 6,	-6.3_4			-5.7_1	-8.4_0	−6.1	38.0	0 45 44.1
Dec. 15,	-6.4_2			-6.7_1	-7.6_0	−6.5	45.8	−0 52 52.3
1863, Aug. 28,	-9.6_1					−9.6	11.6	+0 49 2.0
Sept. 27,	-8.4_3			-8.9_2	-8.4_3	−8.5	61.5	0 29 53.0
Nov. 17,	-8.1_2			-8.7_4	-9.3_4	−8.8	13.6	+0 2 4.8
Dec. 12,	-8.1_1			-8.2_1	-8.8_3	−8.6	53.1	−0 2 1.7
1864, Aug. 7,				-10.7_2		−10.7	53.8	+1 50 43.1
Oct. 1,	-10.8_1				-10.7_3	−10.7	19.0	1 19 8.3
Nov. 12,	-10.2_3			-10.5_4	-9.4_3	−10.1	38.7	0 55 28.6
Dec. 17,				-9.9_1	-9.5_2	−9.7	21.3	+0 49 11.6

REMARKS ON THE PRECEDING TABLE.

The processes to which we have subjected the observations ought, it would seem, to eliminate every source of constant differences between those made at different observatories. But there are still two well-marked cases of systematic differences in the right ascensions, namely, in the Cambridge observations of the first five years, and the Albany observations of the last four. The differences between the corrections finally concluded from all the observations, and those concluded from Cambridge and Albany, are, it will be seen, as follows:

Date.	Conc.—Camb.	Date.	Conc.—Albany.
	s		s
1846, Oct.	+ 0.02	1861, Sept.	— 0.09
Nov.	+ 0.06	Oct.	— 0.06
1847, July,	+ 0.02	Dec.	— 0.05
Aug.	+ 0.03	1862, Aug.	— 0.06
Oct.	+ 0.08	Sept.	— 0.08
Nov.	+ 0.07	Nov.	— 0.07
1848, July,	+ 0.07	Dec.	— 0.09
Aug.	+ 0.07	1863, Sept.	— 0.06
Oct.	+ 0.01	Nov.	— 0.04
Nov.	+ 0.07	Dec.	— 0.01
1849, Sept.	+ 0.06	1864, Oct.	— 0.05
Oct.	+ 0.10	Nov.	— 0.08
Nov.	— 0.03	Dec.	— 0.03
1850, Aug.	+ 0.04		
Oct.	+ 0.05		
Nov.	+ 0.01		

The constancy of signs here exhibited can hardly be attributed to chance in the case of Cambridge, and not at all in the case of Albany. The only cause to which I can attribute it is a habit of registering the transit of Neptune earlier or later than that of a bright star. Such a habit would seem to pertain to the observer rather than the instrument, and, therefore, less to be feared as the number of observers is increased. On account of its possible existence, the weights of the results of any one observatory have not been supposed proportional to the number of observations, but each has been subject to a constant probable error of at least $0^s.02$ when observations were made by eye and ear, and $0^s.01$ when made with chronograph, however great the number of observations.

Albany exhibits the anomaly that the real systematic error seems greater than the probable accidental error. The latter is of the smallest class, as might be anticipated from the facts that the observations are made with a first-class instrument, in a good atmosphere, and are recorded with the electro-chronograph. They have, therefore, been treated in such a way that, while they should enter the absolute longitudes with a very small weight, they should enter the relative longitudes at different times of the year, in other words, the radius vector, with

as much weight as those of any other observatory. This has been effected by applying the constant correction $-0^s.04$ to all the results before combining them.

Anomalies somewhat similar are exhibited by the Paris declinations from 1860 to 1861, and by the Washington declinations of 1861. In the case of Washington, they may be accounted for by the circumstance that the systematic corrections for 1861 depend mainly on observations made in 1863, very few declinations of fundamental stars being observed in 1861–62. But it does not seem so easy to account for the discrepancy between the Paris and Greenwich results. A comparison of them shows that while the Paris observations systematically place the ten fundamental stars adopted as our standard about $0''.8$ farther north than Greenwich, their positions of Neptune, and of some small stars near the equator, substantially agree.

§ 28. The preceding normal right ascensions and declinations are next converted into apparent ecliptic longitudes and latitudes, for the purpose of comparison with the provisional theory. For this purpose Hansen's obliquity of the ecliptic has been adopted, so as to agree with the motion of the ecliptic adopted in the preceding chapter. In the following table we give for each date—1. The longitude from observation, obtained as just stated. 2. The seconds of longitude from provisional theory, as given on p. 43. 3. The excess of the theoretical over the observed longitude. 4, 5, 6. The corresponding quantities relative to the latitude.

GEOCENTRIC APPARENT LONGITUDES AND LATITUDES OF NEPTUNE DERIVED FROM OBSERVATION.

Date.	Longitude. Observation.	Longitude. Theory.	Error of Theory.	Latitude. Observation.	Latitude. Theory.	Error of Theory.
	° ′ ″	″	″			
1795, May 9,	214 37 20.4	19.1	—1.3	+1 50 33.3	34.4	+1.1
1846, Oct. 14,	325 31 35.0	34.9	—0.1	—0 31 55.8	56.0	—0.2
Nov. 14,	325 23 24.2	23.2	—1.0	0 31 43.5	44.0	—0.5
1847, July 26,	329 41 22.9	22.0	—0.9	0 35 24.1	25.9	—1.8
Aug. 17,	329 7 18.9	18.3	—0.6	0 35 45.7	47.7	—2.0
Oct. 8,	327 52 10.4	10.4	0.0	0 35 57.6	58.8	—1.2
Nov. 18,	327 36 56.9	56.3	—0.6	0 35 38.3	38.6	—0.3
1848, July 25,	331 59 6.7	5.0	—1.7	0 39 21.8	22.8	—1.0
Aug. 29,	331 3 16.6	15.8	—0.8	0 39 54.0	55.2	—1.2
Oct. 6,	330 8 55.3	55.3	0.0	0 39 56.8	57.8	—1.0
Nov. 17,	329 59 22.8	22.4	—0.4	0 39 32.3	32.8	—0.5
1849, Sept. 1,	333 15 38.7	38.6	—0.1	0 43 51.8	52.7	—0.9
Oct. 15,	332 15 32.6	32.4	—0.2	0 43 48.6	49.2	—0.6
Nov. 25,	332 4 17.1	16.7	—0.4	0 43 15.7	17.1	—1.4
1850, Aug. 28,	335 39 38.5	38.5	0.0	0 47 41.9	42.7	—0.8
Oct. 15,	334 31 10.3	9.5	—0.8	0 47 39.9	41.1	—1.2
Nov. 20,	334 15 24.4	23.8	—0.6	0 47 8.6	9.5	—0.9
1851, Sept. 2,	337 48 58.5	58.1	—0.4	0 51 32.6	33.7	—1.1
Oct. 14,	336 48 12.7	10.9	—1.8	0 51 30.0	30.0	0.0
Nov. 20,	336 28 32.5	31.9	—0.6	0 50 53.3	54.1	—0.8
1852, Aug. 7,	340 46 10.7	11.0	+0.3	0 54 49.8	51.6	—1.8
Sept. 5,	340 0 11.1	10.3	—0.8	0 55 18.8	19.5	—0.7
Oct. 12,	339 5 43.2	43.0	—0.2	0 55 14.6	14.8	—0.2
Nov. 28,	338 43 24.0	23.4	—0.6	0 54 23.4	23.3	+0.1
1853, Sept. 1,	342 24 48.0	47.7	—0.3	0 58 54.1	55.9	—1.8
Oct. 15,	341 19 0.8	0.2	—0.6	0 58 52.0	52.4	—0.4
Nov. 24,	340 56 4.3	3.0	—1.3	0 58 4.5	4.7	—0.2
1854, Aug. 30,	344 46 18.1	17.8	—0.3	1 2 25.8	27.5	—1.7
Sept. 24,	344 5 33.4	33.2	—0.2	1 2 35.8	37.0	—1.2
Oct. 27,	343 23 17.5	17.3	—0.2	1 2 14.4	15.3	—0.9
Dec. 5,	343 12 3.1	2.8	—0.3	1 1 19.4	19.1	+0.3
1855, Aug. 10,	347 34 55.1	54.2	—0.9	1 5 26.8	28.0	—1.2
Sept. 8,	346 49 57.9	57.0	—0.9	1 6 1.4	1.8	—0.4
Oct. 22,	345 45 7.4	6.2	—1.2	1 5 50.2	50.1	+0.1
Nov. 29,	345 24 25.6	25.3	—0.3	1 4 53.7	54.8	—1.1

GEOCENTRIC APPARENT LONGITUDES AND LATITUDES OF NEPTUNE DERIVED FROM OBSERVATION (Cont.).

Date.	Longitude. Observation.	Longitude. Theory.	Error of Theory.	Latitude. Observation.	Latitude. Theory.	Error of Theory.
	° ′ ″	″	″			
1856, Aug. 8,	349 54 4.2	3.3	— 0.9	— 1 8 43.7	44.8	— 1.1
Sept. 13,	348 58 37.9	37.4	— 0.5	1 9 26.5	27.2	— 0.7
Oct. 26,	347 56 49.5	48.8	— 0.7	1 9 7.1	8.2	— 1.1
Nov. 17,	347 40 53.7	53.1	— 0.6	1 8 34.0	35.3	— 1.3
1857, Aug. 13,	352 5 16.8	16.5	— 0.3	1 12 5.6	6.2	— 0.6
Sept. 21,	351 4 3.1	2.0	— 1.1	1 12 45.6	46.1	— 0.5
Oct. 24,	350 16 10.7	9.6	— 1.1	1 12 28.3	28.3	0.0
Dec. 8,	349 54 2.4	1.4	— 1.0	1 11 11.8	11.8	0.0
1858, Aug. 18,	354 16 21.7	20.9	— 0.8	1 15 19.7	21.0	— 1.3
Sept. 23,	353 19 17.3	17.2	— 0.1	1 15 56.1	56.6	— 0.5
Oct. 28,	352 28 49.3	49.2	— 0.1	1 15 34.2	34.8	— 0.6
Dec. 12,	352 8 48.3	46.7	— 1.6	1 14 11.6	11.8	— 0.2
1859, Aug. 21,	356 30 3.7	2.9	— 0.8	1 18 25.2	25.8	— 0.6
Sept. 23,	355 37 45.0	44.6	— 0.4	1 18 59.5	60.0	— 0.5
Nov. 8,	354 34 30.3	29.4	— 0.9	1 18 22.8	23.0	— 0.2
Dec. 14,	354 22 53.5	52.5	— 1.0	1 17 8.5	9.3	— 0.8
1860, Aug. 20,	358 47 47.9	48.1	+ 0.2	1 21 17.0	17.7	— 0.7
Sept. 23,	357 54 28.9	28.1	— 0.8	1 21 55.4	56.4	— 1.0
Oct. 31,	356 58 23.5	22.4	— 1.1	1 21 31.1	32.2	— 1.1
Dec. 13,	356 36 25.2	24.7	— 0.5	1 20 4.5	4.6	— 0.1
1861, Aug. 22,	1 2 43.6	42.4	— 1.2	1 24 4.8	6.0	— 1.2
Sept. 18,	0 21 9.6	7.6	— 2.0	1 24 41.8	42.2	— 0.4
Oct. 30,	359 16 40.6	38.4	— 2.2	1 24 24.0	24.6	— 0.6
Dec. 7,	358 50 4.3	3.3	— 1.0	1 23 7.0	7.9	— 0.9
1862, Aug. 24,	3 17 37.0	34.7	— 2.3	1 26 46.0	46.7	— 0.7
Sept. 23,	2 31 9.8	7.7	— 2.1	1 27 24.2	25.7	— 1.5
Nov. 6,	1 25 28.0	26.1	— 1.9	1 26 56.1	57.3	— 1.2
Dec. 15,	1 4 11.5	10.0	— 1.5	1 25 29.0	30.0	— 1.0
1863, Aug. 28,	5 29 46.2	46.2	0.0	1 29 22.8	23.7	— 0.9
Sept. 27,	4 42 51.8	49.6	— 2.2	1 29 59.4	60.3	— 0.9
Nov. 17,	3 30 59.6	58.0	— 1.6	1 29 12.1	12.5	— 0.4
Dec. 12,	3 18 20.4	18.2	— 2.2	1 28 12.1	12.4	— 0.3
1864, Aug. 7,	8 9 22.8	20.6	— 2.2	1 30 52.9	53.7	— 0.8
Oct. 1,	6 52 59.8	56.7	— 3.1	1 32 26.8	27.0	— 0.2
Nov. 12,	5 51 40.4	37.8	— 2.6	1 31 48.0	49.1	— 1.1
Dec. 17,	5 32 30.3	27.7	— 2.6	— 1 30 22.6	23.1	— 0.5

CHAPTER IV.

RESULTS OF THE COMPARISON OF THE THEORETICAL WITH THE OBSERVED POSITIONS OF NEPTUNE.

§ 29. The first question of the present chapter will be whether the observations of Neptune can be satisfied within the limits of their probable errors by suitable changes in the elements of the orbit of Neptune and the masses of the disturbing planets.

No admissible change in the mass either of Jupiter or Saturn will sensibly affect the perturbations of Neptune. The mass of Uranus will, therefore, be the only one the correction of which need be taken into account.

The errors of the provisional latitude of Neptune are so small that the errors of the longitude in orbit may be taken as sensibly the same with the errors of ecliptic longitude. The latter give equations of condition between the following unknown quantities.

Correction of the mean longitude of Neptune.
" " mean motion of Neptune.
" " eccentricity $\times$ sin. perihelion of Neptune.
" " eccentricity $\times$ cos. perihelion of Neptune.
" " mass of Uranus.

But if we attempt to solve by least squares the equations between these corrections, we shall be met with the difficulty set forth in the introduction, and our normal equations will be equivalent to only three, unless we include a great number of decimals in the computation. We shall, therefore, make a linear transformation of the unknown quantities, on the principles already referred to, and suggested by the following considerations.

The true longitude of Neptune has been less than its mean longitude, and its true motion has been greater than its mean motion, ever since its optical discovery. From these circumstances the difficulty in question arises. We may obviate it by substituting for the mean longitude and mean motion of Neptune during an entire revolution its average longitude and heliocentric motion during the period of the modern observations. Suppose an imaginary planet to move uniformly in the orbit of Neptune in such a way that its average longitude and motion have been the same as the average longitude and motion of Neptune during the last nineteen years, and let x be its longitude, 1850, Jan. 0, and x' its annual motion. We may then make the eccentricity and perihelion of Neptune to depend analytically upon the deviation of its motion from that of the hypothetical planet, as it must depend really, *because this deviation is the only real datum which we possess to reason from,* the Lalande observations excepted. It is to be remarked

that both the longitude and motion of the hypothetical planet are entirely arbitrary.

For the differential coefficients of the elements with respect to the heliocentric co-ordinates, we have

$$\frac{dv}{d\varepsilon} = 1 + 2\,k \cos l + 2\,h \sin l.$$
$$\frac{dv}{dn} = t \cdot \frac{dv}{d\varepsilon}.$$
$$\frac{dv}{dh} = -2 \cos l - \tfrac{5}{2}\,h \sin 2\,l - \tfrac{5}{2}\,k \cos 2\,l.$$
$$\frac{dv}{dk} = \quad 2 \sin l + \tfrac{5}{2}\,k \sin 2\,l - \tfrac{5}{2}\,h \cos 2\,l.$$
$$\frac{1}{a}\,\frac{dr}{d\varepsilon} = k \sin l - h \cos l.$$
$$\frac{1}{a}\,\frac{dr}{dn} = -\frac{2r}{3an} + \frac{t}{a} \cdot \frac{dr}{d\varepsilon}$$
$$\frac{1}{a}\,\frac{dr}{dh} = -\sin l + h - k \sin 2\,l + h \cos 2\,l.$$
$$\frac{1}{a}\,\frac{dr}{dk} = -\cos l + k - h \sin 2\,l - k \cos 2\,l.$$

In accordance with what has been proposed, we shall substitute for ε and n the quantities x and x', connected with them by the relations

$$\begin{aligned} x &= \varepsilon + \alpha h + \beta k \\ x' &= n + \alpha' h + \beta' k \end{aligned} \tag{1}$$

α and β being approximately the average values of $-2 \cos l$ and $+ 2 \sin l$ during the last nineteen years, and α' and β' the average values of $2\,n \sin l$ and $2\,n \cos l$ during the same time. We shall take

$$\begin{aligned} \alpha &= -1.77 \qquad & \alpha' &= -0.018 \\ \beta &= -0.85 \qquad & \beta' &= +0.073. \end{aligned} \tag{2}$$

Then, considering v as a function of x, y, h, and k, and enclosing the new differential coefficients in parentheses, we have, by suitable transformations,

$$\begin{gathered} \left(\frac{dv}{dx}\right) = \frac{dv}{d\varepsilon};\quad \left(\frac{dv}{dx'}\right) = \frac{dv}{dn};\quad \left(\frac{dr}{dx}\right) = \frac{dr}{d\varepsilon};\quad \left(\frac{dr}{dx'}\right) = \frac{dr}{dn} \\ \left(\frac{dv}{dh}\right) = \frac{dv}{dh} - (\alpha + \alpha' t)\,\frac{dv}{d\varepsilon} \\ \left(\frac{dv}{dk}\right) = \frac{dv}{dk} - (\beta + \beta' t)\,\frac{dv}{d\varepsilon} \\ \frac{1}{a}\left(\frac{dr}{dh}\right) = \frac{1}{a}\,\frac{dr}{dh} - (\alpha + \alpha' t) \cdot \frac{1}{a}\,\frac{dr}{d\varepsilon} + \tfrac{2}{3}\,\alpha' \cdot \frac{r}{an} \\ \frac{1}{a}\left(\frac{dr}{dk}\right) = \frac{1}{a}\,\frac{dr}{dk} - (\beta + \beta' t) \cdot \frac{1}{a}\,\frac{dr}{d\varepsilon} + \tfrac{2}{3}\,\beta' \cdot \frac{r}{an} \end{gathered} \tag{3}$$

Putting λ for the geocentric longitude, and Δ for the distance from the earth, the differential coefficients of the geocentric with respect to the heliocentric co-ordinates will be

$$\begin{aligned} \frac{d\lambda}{dv} &= \frac{r}{\Delta}\cos(v-\lambda), \\ a\frac{d\lambda}{dr} &= \frac{a}{\Delta}\sin(v-\lambda); \end{aligned} \tag{4}$$

and the coefficients of the equations of conditions will be

$$\begin{aligned} \frac{d\lambda}{dx} &= \frac{d\lambda}{dv}\ \frac{dv}{d\varepsilon} + a\frac{d\lambda}{dr}\ \frac{1}{a}\ \frac{dr}{d\varepsilon} \\ \frac{d\lambda}{dx'} &= \frac{d\lambda}{dv}\ \frac{dv}{dn} + a\frac{d\lambda}{dr}\ \frac{1}{a}\ \frac{dr}{dn} \\ \left(\frac{d\lambda}{dh}\right) &= \frac{d\lambda}{dv}\left(\frac{dv}{dh}\right) + a\frac{d\lambda}{dr}\ \frac{1}{a}\left(\frac{dr}{dh}\right) \\ \left(\frac{d\lambda}{dk}\right) &= \frac{d\lambda}{dv}\left(\frac{dv}{dk}\right) + a\frac{d\lambda}{dr}\ \frac{1}{a}\left(\frac{dr}{dk}\right) \end{aligned} \tag{5}$$

The perturbations in the geocentric longitude of Neptune produced by Uranus will be—

1. Perturbations of the true heliocentric longitude multiplied by $\frac{d\lambda}{dv}$;

2. Perturbations of radius vector multiplied by $\frac{d\lambda}{dr}$, for which has been taken $\delta \log r \times \frac{a}{M}\ \frac{d\lambda}{dr}$

Of course the effect of the long-period and secular perturbations of the elements produced by the action of Uranus must be included in the perturbations of Neptune.

Representing by μ the factor by which the assumed mass of Uranus must be multiplied, so that the true mass shall be

$$\frac{1+\mu}{21000},$$

the computed perturbations produced by Uranus will be the coefficients of μ in the equations of condition.

§ 30. The residuals in longitude thus give the following equations between the unknown quantities, which are numbered in the order of time, but grouped somewhat differently.

No.	Date.	Equation.					″	P.	M.
1	1795, May 9,	$0 = 1.02\delta x$	$-55.7\delta x'$	$+2.454\delta h$	$+3.742\delta k$	$+34.6\mu$	-1.3	½	¼
4	1847, July 26,	1.02	−2.2	+0.009	−0.001	+1.17	−0.9	4	2
5	1847, Aug. 17,	1.04	−2.4	+0.010	+0.003	+1.34	−0.6	10	5
2	1846, Oct. 14,	1.02	−3.8	+0.035	+0.024	+1.79	−0.1	6	2
6	47, Oct. 8,	1.03	−2.7	+0.012	+0.014	+1.66	0.0	8	3
3	1846, Nov. 14,	1.01	−3.7	+0.034	+0.025	+1.82	−1.0	7	2
7	47, Nov. 18,	1.01	−2.7	+0.011	+0.017	+1.73	−0.6	7	2
8	1848, July 25,	1.04	−1.2	−0.011	−0.008	+1.16	−1.7	5	2
9	1848, Aug. 29,	1.04	−1.4	−0.010	0.000	+1.39	−0.8	8	3
12	49, Sept. 1,	1.04	−0.4	−0.027	−0.006	+1.47	−0.1	6	2
15	50, Aug. 28,	1.04	+0.7	−0.042	−0.011	+1.55	0.0	5	2
10	1848, Oct. 6,	1.03	−1.7	−0.008	+0.007	+1.61	0.0	8	3
13	49, Oct. 15,	1.03	−0.7	−0.026	+0.002	+1.69	−0.2	8	3
16	50, Oct. 15,	1.03	+0.4	−0.041	−0.002	+1.79	−0.8	7	2
11	1848, Nov. 17,	1.01	−1.7	−0.009	+0.010	+1.68	−0.4	4	1
14	49, Nov. 25,	1.01	−0.7	−0.026	+0.005	+1.74	−0.4	6	2
17	50, Nov. 20,	1.01	+0.4	−0.041	+0.001	+1.85	−0.6	7	2
21	1852, Aug. 7,	1.04	+3.0	−0.062	−0.020	+1.85	+0.3	3	1
18	1851, Sept. 2,	1.04	+1.7	−0.054	−0.013	+1.76	−0.4	6	2
22	52, Sept. 5,	1.04	+2.8	−0.063	−0.014	+2.00	−0.8	5	2
25	53, Sept. 1,	1.04	+3.9	−0.069	−0.016	+2.31	−0.3	5	2
19	1851, Oct. 14,	1.03	+1.4	−0.054	−0.005	+1.95	−1.8	4	1
23	52, Oct. 12,	1.03	+2.5	−0.063	−0.008	+2.16	−0.2	5	2
26	53, Oct. 15,	1.04	+3.5	−0.070	−0.008	+2.44	−0.6	6	2
20	1851, Nov. 20,	1.01	+1.3	−0.053	−0.003	+2.00	−0.6	4	1
24	52, Nov. 28,	1.01	+2.4	−0.062	−0.004	+2.22	−0.6	4	1
27	53, Nov. 24,	1.01	+3.4	−0.069	−0.004	+2.53	−1.3	5	2
28	1854, Aug. 30,	1.04	+5.0	−0.072	−0.016	+2.62	−0.3	6	2
32	55, Aug. 10,	1.04	+6.1	−0.071	−0.018	+2.89	−0.9	8	3
36	56, Aug. 8,	1.04	+7.2	−0.067	−0.017	+3.31	−0.9	8	3
29	1854, Sept. 24,	1.04	+4.8	−0.073	−0.012	+2.75	−0.2	4	1
33	55, Sept. 8,	1.04	+6.0	−0.072	−0.014	+3.11	−0.9	9	3
37	56, Sept. 13,	1.05	+7.0	−0.070	−0.011	+3.44	−0.5	9	3
30	1854, Oct. 27,	1.03	+4.5	−0.073	−0.006	+2.84	−0.2	6	2
34	55, Oct. 22,	1.04	+5.6	−0.074	−0.006	+3.14	−1.2	7	2
38	56, Oct. 26,	1.03	+6.6	−0.072	−0.004	+3.57	−0.7	9	3
31	1854, Dec. 5,	1.01	+4.4	−0.072	−0.004	+2.85	−0.3	4	1
35	55, Nov. 29,	1.02	+5.4	−0.074	−0.003	+3.17	−0.3	8	3
39	56, Nov. 17,	1.02	+6.5	−0.072	−0.002	+3.59	−0.6	8	3
40	1857, Aug. 13,	1.04	+8.2	−0.061	−0.014	+3.83	−0.3	7	2
44	58, Aug. 18,	1.04	+9.3	−0.052	−0.011	+4.39	−0.8	9	3
48	59, Aug. 21,	1.04	+10.3	−0.040	−0.007	+4.94	−0.8	9	3
41	1857, Sept. 21,	1.04	+8.0	−0.065	−0.007	+3.97	−1.1	9	3
45	58, Sept. 23,	1.05	+9.1	−0.056	−0.005	+4.51	−0.1	9	3
49	59, Sept. 23,	1.05	+10.1	−0.044	−0.002	+5.05	−0.4	10	3
42	1857, Oct. 24,	1.04	+7.7	−0.067	−0.002	+4.05	−1.1	6	2
46	58, Oct. 28,	1.04	+8.8	−0.059	+0.001	+4.57	−0.1	10	3
50	59, Nov. 8,	1.03	+9.7	−0.047	+0.005	+5.11	−0.9	9	3
43	1857, Dec. 8,	1.01	+7.5	−0.066	+0.001	+4.09	−1.0	9	3
47	58, Dec. 12,	1.01	+8.5	−0.058	+0.004	+4.55	−1.6	8	3
51	59, Dec. 14,	1.02	+9.5	−0.047	+0.007	+5.09	−1.0	8	3
52	1860, Aug. 20,	1.04	+11.4	−0.024	−0.004	+5.56	+0.2	6	2
56	61, Aug. 22,	1.04	+12.5	−0.005	−0.001	+6.16	−1.2	6	2
60	62, Aug. 24,	1.04	+13.5	+0.016	+0.003	+6.79	−2.3	9	3

No.	Date.	Equation.						P.	M.
						$''$	$''$		
53	1860, Sept. 23,	$0 = 1.05\delta x$	$+11.2\delta x'$	$-0.028\delta h$	$+0.002\delta k$	$+5.67\mu$	-0.8	10	3
57	61, Sept. 18,	1.05	+12.3	−0.009	+0.004	+6.26	−2.0	11	3
61	62, Sept. 23,	1.05	+13.4	+0.012	+0.008	+6.88	−2.1	11	3
54	1860, Oct. 31,	1.04	+10.8	−0.033	+0.008	+5.71	−1.1	9	3
58	61, Oct. 30,	1.04	+11.9	−0.015	+0.011	+6.31	−2.2	10	3
62	62, Nov. 6,	1.04	+12.9	+0.005	+0.015	+6.89	−1.9	11	3
55	1860, Dec. 13,	1.02	+10.5	−0.033	+0.011	+5.68	−0.5	4	1
59	61, Dec. 7,	1.02	+11.6	−0.016	+0.014	+6.25	−1.0	11	3
63	62, Dec. 15,	1.02	+12.6	+0.004	+0.018	+6.81	−1.5	10	3
64	1863, Aug. 28,	1.04	+14.6	+0.040	+0.006	+7.42	0.0	4	1
68	64, Aug. 7,	1.04	+15.6	+0.070	+0.007	+7.94	−2.2	5	2
65	1863, Sept. 27,	1.05	+14.4	+0.036	+0.012	+7.50	−2.2	10	4
69	64, Oct. 1,	1.05	+15.4	+0.063	+0.015	+8.16	−3.1	8	3
66	1863, Nov. 17,	1.04	+13.9	+0.028	+0.019	+7.49	−1.6	9	3
70	64, Nov. 12,	1.04	+15.0	+0.054	+0.022	+8.18	−2.6	10	4
67	1863, Dec. 12,	1.02	+13.7	+0.027	+0.021	+7.45	−2.2	9	3
71	64, Dec. 17,	1.02	+14.7	+0.052	+0.024	+8.13	−2.6	8	3

In order to lessen the labor of solving these equations, they have been divided into groups, with respect to the years of observation, and the difference of heliocentric longitude of the earth and planet. The nineteen years of modern observations have been divided into seven groups, of which the first and last each include two years, and each of the intermediate ones three years. Then, in each group of years, the equations which pertain to corresponding times of the year are grouped together, and will be combined into one.

The numbers in column P. are assumed as the "measure of precision" of the residuals of each equation. These numbers were inferred from the numbers and excellence of the observations on which each normal was founded, the unit of precision was assumed to correspond to the probable error $1''.5$, and no equation was allowed to have a precision exceeding 11. Hence the assumed probable error of each equation is $\frac{1''.5}{P}$. But the residuals left after the final solution show that the measures of precision attached to the modern positions are too great, and that their probable errors are really about $\frac{2''.4}{P}$.

Column M. gives the number by which the individual equations must be multiplied in order that when those of each group are added together, the precision of their sum may be 2. It is approximately $\frac{P}{2\sqrt{n}}$, n being the number of individual equations in the group.

To make the solution more convenient with respect to decimals, the coefficients of $\delta x'$ will all be multiplied by 10, and those of δh and δk divided by 10, after condensing the equations in the manner proposed.

Thus the following twenty-nine homogeneous equations are obtained:

$0 = 0.25\delta x$	$-\ 1.39 \times 10x'$	$+\ 6.14\frac{\delta h}{10}$	$+\ 9.36\frac{\delta k}{10}$	$+\ \overset{\prime\prime}{8.6}\mu$	$-\ \overset{\prime\prime}{0.3}$	
2.04	− 0.44	+ 0.18	− 0.02	+ 2.3	− 1.8	
5.20	− 1.20	+ 0.50	+ 0.15	+ 6.7	− 3.0	
5.13	− 1.57	+ 1.06	+ 0.90	+ 8.6	− 0.2	
4.04	− 1.28	+ 0.90	+ 0.84	+ 7.1	− 3.2	
2.08	− 0.24	− 0.22	− 0.16	+ 2.3	− 3.4	
7.28	− 0.36	− 1.68	− 0.34	+ 10.2	− 2.6	
8.24	− 0.64	− 1.84	+ 0.23	+ 13.5	− 2.2	
5.05	− 0.23	− 1.43	+ 0.22	+ 8.9	− 2.4	
1.04	+ 0.30	− 0.62	− 0.20	+ 1.8	+ 0.3	
6.24	+ 1.68	− 3.72	− 0.86	+ 12.1	− 3.0	
5.16	+ 1.34	− 3.20	− 0.37	+ 11.2	− 3.4	
4.04	+ 1.05	− 2.53	− 0.15	+ 9.3	− 3.8	
8.33	+ 4.99	− 5.58	− 1.37	+ 23.8	− 6.0	
7.31	+ 4.38	− 4.99	− 0.87	+ 22.1	− 4.4	(7)
7.23	+ 4.00	− 5.10	− 0.36	+ 22.7	− 4.9	
7.13	+ 4.01	− 5.10	− 0.19	+ 23.1	− 3.0	
8.32	+ 7.52	− 3.98	− 0.82	+ 35.7	− 5.4	
9.42	+ 8.16	− 4.95	− 0.42	+ 40.6	− 4.8	
8.29	+ 7.09	− 4.52	+ 0.14	+ 37.1	− 5.2	
9.10	+ 7.65	− 5.13	+ 0.36	+ 41.2	− 10.8	
7.28	+ 8.83	− 0.10	− 0.01	+ 43.8	− 8.9	
9.44	+ 11.07	− 0.75	+ 0.42	+ 56.4	− 14.7	
9.36	+ 10.68	− 1.29	+ 1.02	+ 56.7	− 15.6	
7.14	+ 8.31	− 0.69	+ 1.07	+ 44.9	− 8.0	
3.11	+ 4.58	+ 1.80	+ 0.20	+ 23.3	− 4.4	
7.35	+ 10.38	+ 3.33	+ 0.93	+ 54.5	− 18.1	
7.27	+ 10.17	+ 3.07	+ 1.45	+ 55.2	− 15.2	
6.12	+ 8.52	+ 2.37	+ 1.35	+ 46.7	− 14.4	

§ 31. Treating these equations by the method of least squares, but leaving μ indeterminate for the present, we have the four normals

$1277.71x$	$+\ 935.29(10x')$	$-\ 350.59 \cdot \frac{\delta h}{10}$	$+\ 22.46\frac{\delta k}{10}$	$+\ \overset{\prime\prime}{5431.7}\mu$	$-\ \overset{\prime\prime}{1263.39} = 0$	
935.29	+ 1010.58	− 190.60	+ 24.58	+ 5178.1	− 1240.38	(8)
− 350.59	− 190.60	+ 305.88	+ 90.30	− 935.5	+ 146.81	
22.46	+ 24.58	+ 90.30	+ 101.33	+ 317.9	− 74.89	

The solution of these equations gives the following values of the unknown quantities in terms of μ.

$$
\begin{aligned}
\delta x &= +\ \overset{\prime\prime}{0.650} - \overset{\prime\prime}{2.067}\mu \\
\delta x' &= +\ 0.0800 - 0.342\mu \\
\delta h &= +\ 8.76 - 12.18\mu \\
\delta k &= -\ 3.79 - 7.64\mu
\end{aligned}
\qquad (9)
$$

Substituting these values of the corrections in equations (7), we have the following residuals, which are grouped, as before, according to the time of year of the normals on which the equations were founded. Thus, the first residual of each series of modern observations corresponds to positions of Neptune observed when the planet culminated after $13^h\ 30^m$ during the years to which the series belongs.

	h. m.		h. m.
The second, to observations between	10 30	and	13 30
The third, to observations between	7 30	and	10 30
The fourth, before	7 30		

We first give the residuals from the equations (7), each of which is supposed to be of equal precision; then the numbers by which the errors of observation are multiplied to reduce them to the assumed standard of precision derived from (6), column M.; and, finally, the apparent errors of the theory derived from observations themselves, formed by dividing the residuals of the equations by the measures of precision.

	Residuals of equations.			Actual mean residuals or apparent errors of theory.	
	$''$			$''$	$''$
1st series, 1795,	+ 0.58	— 1.8μ	$\frac{1}{4}$	+ 2.3	— 7.2μ
2d series, 1846–1847,	— 0.7	— 0.6μ	2	— 0.35	— 0.30μ
	— 0.2	— 0.8μ	5	— 0.04	— 0.16μ
	+ 2.4	+ 1.5μ	5	+ 0.48	+ 0.30μ
	— 1.1	+ 1.4μ	4	— 0.28	+ 0.35μ
3d series, 1848–1850,	— 2.3	— 0.7μ	2	— 1.15	— 0.35μ
	+ 0.5	— 1.5μ	7	+ 0.07	— 0.21μ
	+ 1.0	+ 0.6μ	8	+ 0.12	+ 0.08μ
	— 0.7	+ 0.8μ	5	— 0.14	+ 0.16μ
4th series, 1851–1853,	+ 0.8	— 0.4μ	1	+ 0.80	— 0.40μ
	— 0.6	— 0.5μ	6	— 0.10	— 0.08μ
	— 1.6		5	— 0.32	
	— 2.5	+ 0.6μ	4	— 0.62	+ 0.15μ
5th series, 1854–1856,	— 1.0	— 2.7μ	8	— 0.12	— 0.34μ
	— 0.2	— 1.2μ	7	— 0.03	— 0.17μ
	— 1.4	+ 0.4μ	7	— 0.20	+ 0.06μ
	+ 0.4	+ 1.0μ	7	+ 0.06	+ 0.14μ
6th series, 1857–1859,	+ 2.8	— 1.7μ	8	+ 0.35	— 0.21μ
	+ 3.7	— 0.4μ	9	+ 0.41	— 0.05μ
	+ 1.8	+ 0.9μ	8	+ 0.22	+ 0.11μ
	— 3.4	+ 2.2μ	9	— 0.38	+ 0.24μ
7th series, 1860–1862,	+ 2.8	— 1.4μ	7	+ 0.40	— 0.20μ
	— 0.6	— 0.5μ	9	— 0.07	— 0.06μ
	— 2.5	+ 1.6μ	9	— 0.28	+ 0.18μ
	+ 2.2	+ 1.7μ	7	+ 0.31	+ 0.24μ

	Residuals of equations.			Actual mean residuals or apparent errors of theory.	
	$''$	$''$		$''$	$''$
8th series, 1863–1864,	$+2.8$	-1.2μ	3	$+0.93$	-0.40μ
	-2.4	-0.9μ	7	-0.34	-0.13μ
	-0.3	$+0.7\mu$	7	-0.04	$+0.10\mu$
	-2.0	$+0.9\mu$	6	-0.33	$+0.15\mu$

§ 32. The coefficients of μ, taken negatively, represent the changes which would be produced in the residuals if we suppose the mass of Uranus to be nothing. It will be seen that these coefficients are generally smaller than the residuals themselves, and that their actual effect on the modern residuals never amounts to more than four-tenths of a second. Supposing that the modern observations cannot be relied on within this limit of error, we should arrive at this remarkable result,—that if the planet Uranus were unknown, its existence could scarcely be inferred from all the observations hitherto made on Neptune, unless these were combined in such a way as to show the systematic error of the theoretical radius vector. In fact, the orbit of Neptune, computed without regard to the perturbations of Uranus, would only exhibit an error of $9''$ when compared with Lalande's position; and a discussion of the modern observations would exhibit no sensible error in the heliocentric longitudes. This circumstance furnishes a very good illustration of the propriety of developing the long-period perturbations, the coefficients of which amount to whole minutes, as perturbations of the elements which shall vanish at the epoch 1850.

Under these circumstances, no reliable correction of the mass of Uranus can be concluded from the motions of Neptune. The solution of the preceding residuals does, indeed, indicate an increase of this mass by one-third, which seems altogether inadmissible, and is certainly very unreliable. Of the twenty-nine residuals, fifteen indicate an increase of the mass, thirteen a diminution, and for one the coefficient of μ vanishes: so that the increase of the mass of Uranus is indicated only by the fact that the residuals which favor it are generally a little larger than those which do not.

§ 33. If Uranus could scarcely be detected from the motions of Neptune, much less can an extra-Neptunian planet, unless it happened to be nearly in conjunction with Neptune at the present time, and to have a much greater mass than Uranus,—a highly improbable combination of circumstances. That there is no present indication of any such action is shown by the smallness of the apparent mean errors of theory in heliocentric longitude and radius vector during the whole period from 1846 to 1864. The following table shows the mean value of these errors during each of the seven series of modern observations, and the error of the geocentric longitude of the Lalande observations, putting $\mu = 0$. The error of radius vector is expressed as error of annual parallax. It will be remembered that the first of the four equations of each series arise from observations made about half-way between the first quadrature and the opposition, the second at opposition, the third between opposition and last quadrature, and the fourth near the last quadrature. Each series, therefore, gives four equations of the first degree between the errors of heliocentric longitude δv, and annual parallax δp.

The coefficient of δv will be sensibly unity, and that of δp will vary from about -0.5 to $+1.0$ in each series.

Error of theory by the Lalande observations.

$+2''.3$

(It will be remembered that the probable error of the Lalande position was estimated at $2''.8$; but, owing to the over-estimate of the comparative precision of the modern observations, the weight assigned to this position in the equations of condition corresponded to a probable error of rather more than $4''$.)

By modern observations.

Limiting dates.	Error of longitude.	Error of parallax.
	$''$	$''$
1846–47,	-0.05	-0.18
1848–50,	-0.08	-0.03
1851–53,	-0.07	$+0.55$
1854–56,	-0.08	0.00
1857–59,	$+0.22$	$+0.23$
1860–62,	$+0.11$	$+0.18$
1863–64,	$+0.02$	$+0.28$

These errors are as small as could be expected if the theory were perfect. There is, therefore, no indication of the action of an extra-Neptunian planet. But this fact does not militate against the existence of such a planet. The perturbations of a planet, and its elliptic elements, develop themselves, not in proportion to the time, but in proportion to the square of the arc described. In order, therefore, to determine the errors of a slow-moving planet with as much accuracy as those of a quick-moving one, we must observe it through a period proportioned to its time of revolution. And we cannot detect a deviation of long period from an elliptic orbit until we have accumulated data much more than sufficient for the exact determination of the elliptic elements. For example, when the position of Neptune was determined from the perturbations of Uranus, the latter planet had been regularly observed through an arc of some 270°. Moreover, the two planets had been in conjunction in 1824. They are also remarkably near each other when in conjunction. Yet, with all these circumstances so favorable to the development of large perturbations, Uranus only wandered about $5''$ from an elliptic orbit during the entire period of the modern observations.

Perturbations will, at first, be developed in proportion to the square of the arc passed over. Therefore, had Uranus been observed through an arc of only 120°, the perturbations by Neptune would have been indicated only by deviations in heliocentric longitude of less than $1''$. It is, therefore, almost vain to hope for the detection of an extra-Neptunian planet from the motions of Neptune before the close of the present century.

§ 34. *Determination of the position of the plane of the orbit of Neptune.*

To determine the corrections of the constants p and q, which determine the

position of the plane of the orbit, we shall divide the residuals of latitude into five groups, the last one including three years, and each of the others four years. To find the heliocentric angular distance of the planet above the plane of its assumed orbit, we shall take an indiscriminate mean of the errors of geocentric latitude of each group, multiply it by 0.98 to reduce it to heliocentric error, and correct it for the mean error in longitude.

The mean errors of geocentric latitude, with the equations to which they give rise, are as follows. The probable errors of each modern mean is estimated at 0″.15: so that the Lalande position is entitled to a precision of $\frac{1}{10}$.

Limiting Dates.	$\delta\beta$	Equation of Condition.		
	″			″
1795,	+ 1.1	$0 = +0.081\delta p$	$-0.058\delta q$	+ 0.11
1846–49,	— 0.97	— 0.866	— 0.500	— 0.96
1850–53,	— 0.75	— 0.934	— 0.358	— 0.75
1854–57,	— 0.71	— 0.978	— 0.208	— 0.71
1858–61,	— 0.67	— 0.999	— 0.052	— 0.68
1862–64,	— 0.79	— 0.996	+ 0.084	— 0.80

The solution of which by least squares gives

$$\delta p = -0''.73\,;\quad \delta q = -0''.41.$$

The residuals, multiplying the first by 10 to reduce it to actual observed error, are

	″
1795,	+ 0.7
1846–49,	— 0.13
1850–53,	+ 0.07
1854–57,	+ 0.09
1858–61,	+ 0.07
1862–64,	— 0.10

So that the Lalande observation is represented within 0″.7, notwithstanding the small weight with which it enters the equations. In fact, if p and q were determined from the modern observations alone, the Lalande position would still be represented within about 0″.7.

§ 35. *Concluded elements of Neptune.*

From equations (1) and (2) of this chapter, we have

$$\delta\varepsilon = \delta x + 1.77\ \delta h + 0.85\ \delta k;$$
$$\delta n = \delta x' + 0.018\delta h - 0.073\delta k;$$

So that, making the mass of Uranus $\frac{1}{21000}$, the concluded corrections to the provisional elements of § 19 are

$$
\begin{aligned}
\delta\varepsilon &= +\ 12''.94 \\
\delta n &= +\ 0.5144 \\
\delta h &= +\ 8.76 \\
\delta k &= -\ 3.79 \\
\delta p &= -\ 0.73 \\
\delta q &= -\ 0.41
\end{aligned}
$$

Applying these corrections to the provisional elements of § 19, they become

$$
\begin{aligned}
\varepsilon &= 335^\circ\ 5'\ 38''.91 \\
n &= 7864.9354 \\
h &= +1201.69 \\
k &= +1275.57 \\
p &= +4909.44 \\
q &= -4137.87
\end{aligned}
$$

CHAPTER V.

TABLES OF NEPTUNE.

§ 36. *Fundamental theory.*

The fundamental theory on which these tables are founded is as follows:

1. *Undisturbed elements of Neptune, referred to the mean ecliptic and equinox of the epoch.*

$$\begin{aligned}
h &= \text{eccentricity} \times \text{sine perihelion} &&= +\ 1201''.69\\
k &= \text{eccentricity} \times \text{cos perihelion} &&= +\ 1275.57\\
p &= \text{sine inclination} \times \text{sine node} &&= +\ 4909.44\\
q &= \text{sine inclination} \times \text{cos node} &&= -4137.87\\
n &= \text{mean motion in } 365\tfrac{1}{4} \text{ days} &&= \quad 7864.935\\
\varepsilon &= \text{mean longitude at epoch} &&= 335^\circ\ 5'\ 38''.91
\end{aligned}$$

Epoch 1850, Jan. 0, Greenwich mean noon.

From these expressions we deduce

$$\begin{aligned}
\pi &= 43^\circ\ 17'\ 30''.3\\
e &= 0.0084962\\
\log a &= 1.4781414\\
\text{Period} &= 164.782 \text{ Julian years.}
\end{aligned}$$

In log a we have included the constants of log r introduced by the action of the planets, and also the effect of the secular variation of the longitude of the epoch, both of which are computed on p. 31.

2. *Secular and long-period perturbations of the above elements.*

These are taken without change from the table p. 39.

The elements being corrected by the addition of these perturbations for the epoch of computation, we thence deduce the elliptic place of the planet.

3. *Perturbations of the co-ordinates.*

To the elliptic place of the planet we apply corrections for periodic perturbations of the co-ordinates, as follows:

To the longitude in orbit,

$$P_{s.1} \sin l + P_{c.1} \cos l + P_{s.2} \sin 2\,l + P_{c.2} \cos 2\,l + \delta v_0.$$

To the logarithm of the radius vector,

$$R_{s.1} \sin l + R_{c.1} \cos l + \delta r_0.$$

To the north latitude, computed with the true longitude in orbit,

$$B_{s.1} \sin v + B_{c.1} \cos v + \delta\beta_0.$$

All these quantities have the same values as in § 19, pp. 40 and 41.

The elliptic values of the co-ordinates being thus corrected, we have the heliocentric co-ordinates resulting from the concluded theory.

To facilitate this computation, the following tables are constructed. They are designed to give the means of determining, for any date between the years 1600 and 2000, the principal auxiliary quantities which will be needed in computing the place of the planet from the above theory. Many of these quantities are modified so that the computer shall be troubled as little as possible with difference of signs. Thus, to all the quantities P_s, P_c, R_s, etc. constants are added so that they shall always be positive, and so that the signs of the products which form the perturbations shall be the same as those of sin l, cos l, etc. Again, constants are added to all the perturbations of the longitude and radius vector, to make them positive.

§ 37. *Data given in the several tables.*

Table I. gives the values of the "epochs and arguments" for the beginning of each fourth year from 1800 to 1952 inclusive, the years 1800 and 1900 beginning with Greenwich mean noon of Jan. 0, and all the other years with that of Jan. 1.

P is simply the number of the four-year cycle before 1900, by which l' and θ' of the next table must be multiplied, or $\frac{1900 - Y}{4}$, adding a unit for fractions.

l is the mean longitude in orbit of Neptune, affected with the long-period perturbations of that element, p. 39, and referred to the mean equinox of 1850.0.

y is the negative of the longitude of the node affected by perturbations, counted on the orbit of the planet from that point which is equally distant from the node of 1850 with the equinox of 1850, and diminished by 1°, the sum of the constants added to the equations of longitude.

θ is the longitude of the node, referred to the mean equinox of the epoch, and diminished by 1′, the constant added to the reduction to the ecliptic.

In the arguments 1 to 9 inclusive, the circle is divided into 400 parts. Representing the mean longitude of a planet, referred to the equinox of 1850.0 by its initial letter, the values of the different arguments are as follows:

$$
\begin{aligned}
\text{Arg. } 1 &= U - N, \\
\text{“ } 2 &= S - N, \\
\text{“ } 3 &= J - N, \\
\text{“ } 4 &= 2S - N, \\
\text{“ } 5 &= S, \\
\text{“ } 6 &= S - 2N, \\
\text{“ } 7 &= 2J - N, \\
\text{“ } 8 &= J, \\
\text{“ } 9 &= J - 2N.
\end{aligned}
$$

Thus, Arg. 1 gives the difference of the mean longitudes of Uranus and Neptune, expressed in parts 100 of which make a quadrant; and so of the other arguments.

At the bottom of the table the expression $\Delta^{(1)}_{(180)}$ is the change in the longitude or the argument during that 180 days which commences with 1850, Jan. 0.

Fact. T gives the change in $\Delta^{(1)}_{(180)}$ during a century: so that the change in any 180-day period within one or two centuries of the epoch may be found by multiplying Fact. T by the fraction of a century after 1850.0 at which the 180-day period commences, and applying it to $\Delta^{(1)}_{(180)}$.

$\Delta^{(2)}_{(180)}$ gives the second difference for any series of 180-day periods within one or two centuries of 1850: so that, knowing the first value of $\Delta^{(1)}_{(180)}$, we can find a series of values by successive addition.

The period of 180 days has been selected as a convenient one for computing a heliocentric ephemeris. If any other period, represented by N days, be preferred, the corresponding values of $\Delta^{(1)}$ and $\Delta^{(2)}$ are found by multiplying

$$\Delta^{(1)}_{(180)} \text{ by } \frac{N}{180},$$

and

$$\Delta^{(2)}_{(180)} \text{ by } \frac{N^2}{180^2}.$$

Table II. gives the change of each longitude and argument for the first day of each month during a four-year cycle. The change in l is given for that cycle which begins with 1900 and ends with 1904. Column l' gives, in units of the second decimal of seconds, the change in column l during one cycle. Hence, multiplying l' by the whole number P of the preceding table, and adding the units of the product to the hundredths of seconds of l, we have the change of mean longitude during the cycle numbered P in Table I. The correction is positive for years before 1900, because the mean motion is diminishing.

θ must be corrected in precisely the same way; but here the correction is negative before 1900.

Rigorously, both y and θ require correction similar to l. But it is not requisite that either of these quantities should be accurate within a second, so long as their sum is exactly equal to the precession diminished by 1° 1′. The four-year changes of both y and θ, which destroy each other, are, therefore, neglected; but the change in θ due to the secular variation of the constant of precession (0″.0227) is allowed for by the correction $P\theta'$.

Table III. gives the reduction from the first to the subsequent days of any month, or the motion of the epochs and arguments during a number of days one less than those on the left of the table.

Table IV. gives the corrections to be applied to the longitudes and arguments for the epochs $1800 + t$ to reduce them to the epochs $1600 + t$, $1700 + t$, and $1900 + t$, respectively. They are expressed in the form

$$a_0 + T \times \text{Fact. } T + T^2 \times \text{Fact. } T^2,$$

in which T is the fraction of a century.

Table V. gives the expressions for the perturbations of the longitude produced by Uranus. To each of the expressions $P_{s.1}$ and $P_{c.1}$ 14″ has been added, and to $P_{s.2}$ and $P_{c.2}$ 3″ has been added. Hence, when these quantities, as given in the

tables, are multiplied by $\sin l$, $\cos l$, $\sin 2\,l$, and $\cos 2\,l$, the sum will be too great by the quantity

$$14'' \sin l + 14'' \cos l + 3'' \sin 2\,l + 3'' \cos 2\,l,$$

which expression has been subtracted from the equation of the centre. The constant 14″ has been added to δv_1.

TABLE VI. gives the principal perturbations of the longitude produced by Saturn, namely,

$$\begin{aligned} & 18''.552 \sin\ (S-N) \\ - & \ 0\ .141 \sin 2\,(S-N) \\ - & \ 0\ .012 \sin 3\,(S-N) \\ + & \ (\text{const.} = 19''.000) \end{aligned}$$

TABLE VII. gives the principal perturbations of the longitude produced by Jupiter, namely,

$$\begin{aligned} & 34''.121 \sin\ (J-N) \\ - & \ 0\ .011 \sin 2\,(J-N) \\ + & \ (\text{const.} = 35''.000) \end{aligned}$$

TABLE VIII. gives the term

$$\begin{aligned} & -0''.524 \cos (2\,S-N) \\ & +\ (\text{const.} = 0''.600) \end{aligned}$$

TABLE IX. gives the terms

$$\begin{aligned} -0''.058 \sin S \quad & +0''.047 \cos S \\ +\ (\text{const.} & = 0''.100) \end{aligned}$$

TABLE X. gives the terms

$$\begin{aligned} +0''.166 \sin (S-2\,N) \quad & +0''.436 \cos (S-2\,N) \\ +\ (\text{const.} & = 0''.500) \end{aligned}$$

TABLE XI. gives the terms

$$\begin{aligned} +0''.783 \sin (2\,J-N) \quad & -0''.164 \cos (2\,J-N) \\ +\ (\text{const.} & = 1''.100) \end{aligned}$$

TABLE XII. gives the terms

$$\begin{aligned} -0''.101 \sin J \quad & +0''.097 \cos J \\ +\ (\text{const.} & = 0''.200) \end{aligned}$$

TABLE XIII. gives the terms

$$\begin{aligned} +0''.326 \sin (J-2\,N) \quad & +0''.297 \cos (J-2\,N) \\ +\ (\text{const.} & = 0''.500) \end{aligned}$$

TABLE XIV. will be more easily understood after we have explained the table of equation of the centre.

TABLE XV. is composed of the four following parts:

1. The equation of the centre in the undisturbed ellipse of 1850.0, or,

$$\begin{array}{lll} + 2551''.117 \sin l & - 2403''.358 \cos \\ + \quad 1.163 \sin 2l & - \quad 18.580 \cos 2l \\ - \quad 0.088 \sin 3l & - \quad 0.104 \cos 3l \end{array}$$

2. The change in the equation of the centre produced by the perturbations of the elements h and k during that revolution of the planet which commenced 1779, Jan. 4, and ends 1943, Oct. 15. This change is represented by

$$2\,\delta k \sin l - 2\,\delta h \cos l,$$

δh and δk being taken from the table on p. 39 for the times corresponding to the various values of l during the period in question.

3. The terms

$$\begin{array}{ll} -14'' \sin l & -14'' \cos l \\ -\ 3 \sin 2l & -\ 3 \cos 2l \end{array}$$

introduced to destroy the effect of the constants added to the values of $P_{s.1}$, $P_{c.1}$, $P_{s.2}$, and $P_{c.2}$ to render them positive.

4. The constant

$$3529'',$$

added to render all the numbers of the table positive.

During the revolution to which Table XV. corresponds, the planet passed from 180° mean longitude, and returned to the same point in the heavens; whence the table begins and ends with this value of l. But since the commencement of the table corresponds to the values of h and k in 1779, and the end to these values in 1943, they do not correspond with each other. The sum of the constants added to Tables V. to XV. inclusive is 1°, which has been subtracted from y in Table I.

Table XIV. is formed by subtracting the values of δh and δk during the revolution of Table XV. from the values of the same elements 164.78 years earlier or later. Or, we have

$$\Delta P_{s.1} = \quad 2\,(\delta k' - \delta k_0)$$
$$\Delta P_{c.1} = -2\,(\delta h' - \delta h_0)$$

$\delta h'$ and $\delta k'$ representing the values of δh and δk at any epoch, and δh_0 and δk_0 their values at that date of the period 1779–1943 when the planet had the same mean longitude as at the epoch in question.

The sum of the sixteen quantities $P_{s.1} \sin l$, $P_{c.1} \cos l$, $P_{s.2} \sin 2l$, $P_{c.2} \cos 2l$, δv ($_1$ to $_9$), l, y, and the equation of Table XV. will give the true distance of the planet from its ascending node, which we represent by u.

Table XVI. gives the reduction to the ecliptic for the years 1800, 1900, and 2000, together with the change of the reduction for a century. The constant

$$60''$$

has been added to render all the numbers of the table positive.

The sum of u, θ, and the reduction to the ecliptic gives the true ecliptic longitude of the planet, referred to the mean equinox of the date.

Tables of the radius vector.

TABLE XVII. gives the values of

$$R_{s.1} + 150, \text{ and } R_{c.1} + 100.$$

The expressions for $R_{s.1}$ and $R_{c.1}$ are given on p. 40, § 19, and the units are those of the seventh place of decimals. $R_{s.1} + 150$ must be multiplied by $\sin l$, and $R_{c.1} + 100$ by $\cos l$, and the products included in the perturbations of $\log r$.

TABLE XVIII. gives the principal terms of the perturbations of the logarithm of the radius vector produced by Uranus, as given on p. 41. The constant added is 209.

TABLE XIX. gives the perturbations of the same element by Saturn, namely,

$$\begin{aligned} &397 \cos (S - N) \\ + \; &4 \cos 2 (S - N) \\ + \; &(\text{const.} = 400) \end{aligned}$$

TABLE XX. gives the perturbations of the same element by Jupiter, namely,

$$\begin{aligned} &701 \cos (J - N) \\ + \; &(\text{const.} = 700) \end{aligned}$$

The units of these tables are those of the seventh place of decimals.

TABLE XXI. is formed of the four following quantities.

1. A constant formed by applying the necessary corrections to the logarithm of the mean distance. We have

Mean motion, including its perturbations,	7864.935
Secular var. long. epoch,	+ 21.443
Elliptic mean motion,	7843.492
To which corresponds	$\log a = 1.4787334$
Constants of perturbations of $\log r$ (p. 31),	— 5920
Negative of constants added to Tables XVIII.–XX.,	— 1309
Constant to be substituted for $\log a$ in expression for log radius vector,	1.4780105

2. The elliptic $\log r - \log a$, namely,

$$\begin{aligned} &+ .0000078 \\ &- .0026857 \cos l \quad - .0025301 \sin l \\ &- .0000014 \cos 2l \quad - .0000235 \sin 2l \end{aligned}$$

3. The effects of the perturbations of h, k and a during the same revolution to which Table XV. corresponds, represented by

$$-\frac{M\delta h}{\sin 1''} \sin l \quad - \frac{M\delta k}{\sin 1''} \cos l + \delta \log a,$$

M being the modulus of the common system of logarithms.

4. The terms

$$-150 \sin l \quad -100 \cos l$$

introduced to destroy the effects of the constants added to $R_{s.1}$ and $R_{c.1}$.

TABLE XXII. gives the values of $B_{s.1}$ and $B_{c.1}$ (p. 40). The constant $0''.30$ has been added to each of these quantities to render them positive.

TABLES XXIII. and XXIV. give the perturbations of the latitude produced by Saturn and Jupiter respectively, no constants being added.

TABLE XXV. gives the values of log sin i, to be added to log sin u in order to obtain the elliptic latitude. They, as well as θ, have been obtained from the formulæ

$$\sin i \sin \theta = p + \delta p + 0''.30$$
$$\sin i \cos \theta = q + \delta q - 0\ .30$$

The values of δp and δq being taken from the table p. 39, and the corrections $\pm 0''.30$ being applied to destroy the effect of the constants added to $B_{s.1}$ and $B_{c.1}$.

§ 38. *Elementary precepts for the use of the tables.*

Express the date for which the position of Neptune is required, in years, months, and days of Greenwich mean time, according to the Gregorian Calendar.

If the date is between 1800 and 1955 inclusive, enter Table I. with the year, or the first preceding year found therein, and take out the values of l, y, θ, and Arguments 1–9 inclusive. Note also the value of P. If the date is not between the above limits, enter as if the number of the century were 18.

Enter Table II. with the excess of the actual year above that with which Table I. was entered, and with the month. Write the values of l, y, θ, and the arguments under those from Table I. Multiply l' and θ', the former interpolated to the day of the month, by P of Table I., and write the units of the product under the hundredths of seconds of l and θ, paying attention to the algebraic signs.

Enter Table III. with the day of the month, and write down l, &c., under the former values.

If the date is without the limits 1800–1955, enter Table IV. with the century, write the principal quantities under their proper heads, as before; multiply column "Fact. T" by the entire fraction of the century represented by the date, and column "Fact. T^2" by the square of this fraction, and write the products under their proper heads.

Add up all the partial values of l, y, θ, and the arguments thus obtained, attending to the algebraic signs of the products, subtracting from the arguments as many times 400 as possible, and we have the final values of those quantities.

Enter Table V. with the final value of Arg. 1, and take from it the five quantities there found. Multiply the first four of them as follows, using logarithms or natural numbers as may be most convenient:

$P_{s.1}$ by sine of l,
$P_{c.1}$ by cosine of l,
$P_{s.2}$ by sine of $2\,l$,
$P_{c.2}$ by cosine of $2\,l$.

But if the date is earlier than 1779 or later than 1943, $P_{s.1}$ and $P_{c.1}$ must first be corrected from Table XIV.

Write these four products under each other, remembering that their algebraic signs will be the same as those of the sine and cosine of l and $2\,l$, unless the corrections make $P_{s.1}$ or $P_{c.1}$ negative. Write under them the fifth quantity, δv_1.

Enter Tables VI. to XIII. inclusive, with the arguments at the top of each. Take out the eight remaining values of δv.

Enter Table XV. with l, first reducing the minutes and seconds to decimals of a degree, and take out the corresponding equation by interpolation to second differences.

Under these fourteen quantities write l and y, add up the sixteen lines, and call the sum u.

Under u write θ; enter Table XVI. with u (reduced to hundredths of a degree) as the side argument, and the year as the top argument, and take out the reduction to the ecliptic. Add it to u and θ, and the sum will be the heliocentric longitude of Neptune referred to the mean equinox and ecliptic of the date.

Enter Table XVII. with argument 1, and take out the values of $R_{s.1}$ and $R_{c.1}$. If the date is previous to 1779 or subsequent to 1943, multiply the values of $\Delta P_{s.1}$ and $\Delta P_{c.1}$ from Table XIV. by 10.53, and correct $R_{s.1}$ and $R_{c.1}$ as follows:

$$R_{s.1} \text{ by } \quad 10.53\,\Delta P_{c.1},$$
$$R_{c.1} \text{ by } -10.53\,\Delta P_{s.1},$$

adding the units of these products to the last figures of $R_{s.1}$ and $R_{c.1}$. Then multiply

$$R_{s.1} \text{ by sine of } l,$$
$$R_{c.1} \text{ by cosine of } l,$$

and write down the products with the algebraic sign of sine l and cos l respectively.

Enter Tables XVIII. to XX. with their proper arguments, and write the results under the products thus found.

Enter Table XXI. with the argument l, and take out the corresponding number, the first two figures of which are at the top of each column. Write it so that the last figure (the seventh place of decimals) shall be under the last figures of the former numbers.

The sum of the six numbers thus found will be the common logarithm of the radius vector of Neptune.

Enter Table XXII. with argument 1, and take out $B_{s.1}$ and $B_{c.1}$. Multiply the former by sin l and the latter by cos l.

Enter Tables XXIII. and XXIV. with their proper arguments, and take out the corresponding numbers, applying the proper algebraic signs.

Take the sine of i from Table XXV., and multiply it by the sine of u (u having already been found).

The sum of the five quantities thus found, each taken with its proper algebraic sign, will be the north latitude of Neptune above the plane of the ecliptic of the date.

Thus we shall have the heliocentric co-ordinates of the planet. The computer can then pass to the geocentric place by the method which he prefers.

If an ephemeris is wanted during a series of years, it will not be necessary to

take the arguments from Tables I.–IV. more than once in three or four, or even five, years. The intervals of computation are first to be chosen, and need not be less than 180 days for the heliocentric place. Then compute the values of l, y, θ, and the arguments for the first date of the series, and again for a date an integral number of intervals (not generally exceeding ten) later. The longitudes and arguments for the intermediate dates may then be found by continual addition of the differences for 180 days (if this is the interval) from the bottom of Table I.

§ 39. *Examples of the use of the tables.*

As a first example, we will compute an ephemeris of the heliocentric positions of Neptune for the years 1865 to 1868 inclusive. The intervals of computation will be 180 days, and we commence with the date 1864, Oct. 13, and end with 1869, March 21, between which are nine of the assumed intervals. We first compute the epochs and arguments for the extreme dates as follows:

1. For 1864, October 13.

	l	y	θ	Arg. 1	2
Table II., 1864,	5 40 58.30	228 54 54.37	130 15 49.25	91.96	199.49
Table III., Year 0, Oct.,	1 38 19.86	7.88	29.82	1.75	8.37
Fact. × 9,	.14		— .01		
Table IV., Day 13,	4 18.39	0.35	1.31	0.08	0.37
Epochs & Args. 1864, Oct. 13,	7 23 36.69	228 55 2.60	130 16 20.37	93.79	208.23

Arg.	3	4	5	6	7	8	9
Table II., 1864,	243.86	5	206	193	93.9	250	237
Table III., Year 0, Oct.,	23.47	19	10	7	48.8	25	22
Table IV., Day 13,	1.03	1	0	0	2.2	1	1
For 1864, Oct. 13.	268.36	25	216	200	144.9	276	260

2. For 1869, March 21.

	l	y	θ	Arg. 1	2
Table II., 1868,	14 25 17.73	228 55 36.39	130 18 28.26	101.30	244.11
Table III., Year 1, March,	2 32 31.25	12.23	46.25	2.72	12.98
Fact. × 8,	.19		— .01		
Table IV., Day 21,	7 10.64	0.57	2.18	0.13	0.61
For 1869, March 21,	17 4 59.81	228 55 49.19	130 19 16.68	104.15	257.70

Arg.	3	4	5	6	7	8	9
Table II., 1868,	369.03	104	260	228	353.9	385	353
Table III., Year 1, March,	36.41	29	16	10	75.7	39	34
Table IV., Day 21,	1.71	1	1	0	3.6	2	2
For 1869, March 21,	7.15	134	277	238	33.2	26	389

The epochs and arguments for the intermediate dates are now formed by successive additions of the change in 180 days, deduced from Table I. T, the fraction of a century after 1850, being 0.148, the first differences for 180 days, with the arguments, are found to be as follows:

	$\triangle_{180}$	1864, Oct. 13	1865, Apr. 11	1866, Apr. 6	1868, Sept. 22	1869, Mar. 21
	° ′ ″					
l	1 4 35.908	7 23 36.69	8 28 12.598	9 32 48.505	16 0 23.920	17 4 59.818
$\triangle l$	—.0012	1 4 35.908	1 4 35.907	1 4 35.905	1 4 35.898	
y	5.177	228 55 2.60	228 55 7.777	228 55 18.131	228 55 44.013	228 55 49.189
θ	19.590	130 16 20.37	130 16 39.960	130 16 59.550	130 18 57.093	130 19 16.684
Arg. 1	1.150	93.79	94.940	96.090	102.990	104.140
2	5.497	208.23	213.727	219.224	252.206	257.703
3	15.421	268.36	283.781	299.202	391.729	7.151
4	12.20	25.	37.2	49.4	122.6	134.8
5	6.7	216.	222.7	229.4	269.6	276.3
6	4.3	200.	204.3	208.6	234.4	238.7
7	32.03	144.9	176.93	208.96	1.14	33.17
8	16.6	276.	292.6	309.2	8.8	25.4
9	14.2	260.	274.2	288.4	373.6	387.8

	1864, Oct. 13	1865, Apr. 11	1866, Apr. 6	1868, Sept. 22	1869, Mar. 21
	° ′	° ′	° ′	° ′	° ′
$2l$	14 47	16 56	19.6	32 1	34 10
	°	°	°	°	°
l (in Dec. of deg.)	7.3935	8.4702	9.5468	16.0066	17.0833

LONGITUDE.

	1864, Oct. 13	1865, Apr. 11	1866, Apr. 6	1868, Sept. 22	1869, Mar. 21
	″	″	″	″	″
$P_{s.1}$	23.76	24.04	24.30	25.57	25.72
$P_{c.1}$	22.50	22.14	21.77	19.35	18.93
$P_{s.2}$	4.75	4.67	4.59	4.02	3.92
$P_{c.2}$	1.76	1.67	1.59	1.21	1.17
$P_{s.1}\sin l$	3.06	3.54	4.03	7.05	7.55
$P_{c.1}\cos l$	22.32	21.90	21.47	18.60	18.09
$P_{s.2}\sin 2l$	1.21	1.36	1.50	2.13	2.20
$P_{c.2}\cos 2l$	1.70	1.60	1.51	1.03	0.96
δv_1	11.15	11.49	11.83	13.79	14.12
δv_2	16.57	15.01	13.41	5.30	4.26
δv_3	5.03	1.98	0.88	30.58	38.83
δv_4	0.12	0.17	0.23	0.78	0.87
δv_5	0.07	0.07	0.08	0.13	0.14
δv_6	0.06	0.05	0.04	0.04	0.05
δv_7	1.80	1.53	1.15	0.95	1.35
δv_8	0.26	0.29	0.31	0.28	0.25
δv_9	0.06	0.08	0.13	0.64	0.73
Tab. XV.	0 23 59.17	0 24 53.01	0 25 47.59	0 31 29.74	0 32 29.03
l	7 23 36.69	8 28 12.60	9 32 48.50	16 0 23.92	17 4 59.81
y	228 55 2.60	228 55 7.78	228 55 12.96	228 55 44.01	228 55 49.19
u	236 43 41.87	237 49 12.46	238 54 45.62	245 28 58.97	246 34 47.43
θ	130 16 20.37	130 16 39 96	130 16 59.55	130 18 57.09	130 19 16.68
Red. Ecl.	14.23	15.01	15 88	22.33	23.62
Longitude	7 0 16.47	8 6 7.43	9 12 1.05	15 48 18.39	16 54 27.73

Radius Vector.

$R_{s.1}$	22	24	26	41	44
$R_{c.1}$	155	158	163	176	178
$R_{s.1}$ sin l	3		4	11	13
$R_{c.1}$ cos l	154	156	158	169	170
δ log r_1	82	77	73	48	44
δ log r_2	10	17	23	129	154
δ log r_3	366	524	691	1394	1396
Prin. term	1.4750064	1.4749650	1.4749250	1.4747074	1.4746754
log r	1.4750679	1.4750427	1.4750199	1.4748825	1.4748531

Latitude.

log sin u	9.922246	9.927565	9.932667	9.958964	9.962660
log sin i	8.492852	8.492842	8.492831	8.492764	8.492753
log sin β_0	8.415098	8.420407	8.425498	8.451728	8.455413
	″	″	″	″	″
$B_{s.1}$	0.47	0.46	0.45	0.38	0.37
$B_{c.1}$	0.01	0.00	0.00	0.00	0.00
	″	″	″	″	″
$B_{s.1}$ sin l	+0.05	+0.06	+0.07	+0.10	+0.11
$B_{c.1}$ cos l	+0.01	0.00	0.00	0.00	0.00
$\delta\beta_1$	+0.28	+0.26	+0.24	+0.08	+0.05
$\delta\beta_2$	−0.54	−0.56	−0.55	+0.12	+0.25
β_0	−1 29 25.02	−1 30 31.03	−1 31 35.09	−1 37 17.28	−1 38 7.04
Latitude	−1 29 25.22	−1 30 31.27	−1 31 35.33	−1 37 16.98	−1 38 6.63

Inserting the results for the five middle dates, the computations of which have been omitted in printing, for want of space, we have the following heliocentric ephemeris of Neptune:

Date.	Longitude (mean equinox of date).	Logarithm of radius vector.	Latitude.
	° ′ ″		° ′ ″
1864, Oct. 13,	7 0 16.47	1.4750679	−1 29 25.22
1865, Apr. 11,	8 6 7.43	1.4750427	−1 30 31.27
Oct. 8,	9 12 1.05	1.4750199	−1 31 35.33
1866, Apr. 6,	10 17 57.51	1.4749986	−1 32 37.36
Oct. 3,	11 23 56.84	1.4749778	−1 33 37.41
1867, Apr. 1,	12 29 58.92	1.4749567	−1 34 35.41
Sept. 28,	13 36 3.52	1.4749342	−1 35 31.38
1868, Mar. 26,	14 42 10.14	1.4749097	−1 36 25.26
Sept. 22,	15 48 18.39	1.4748825	−1 37 16.98
1869, Mar. 21,	16 54 27.73	1.4748531	−1 38 6.63

These co-ordinates being interpolated to every ten days, and corrected for nutation, the geocentric co-ordinates may then be computed and corrected for aberration in the usual way.

As another example, let us compute the heliocentric position of Neptune for Greenwich mean noon of 1795, May 9, the epoch of the normal place derived from Lalande's two observations.

	l	y	θ	Arg. 1	Arg. 2
	° ′ ″				
Table I., 1892,	66 51 12.69	228 59 48.26	130 34 22.60	157.30	111.85
Table II., 3^y May,	7 16 23.32	0 0 35.01	0 2 12.33	7.77	37.13
$2 \times l'$	.13		—.01		
Table III., Day 9,	0 2 52.26	0.23	0.87	0.05	0.24
Table IV., 1700,	141 31 19.97	359 42 21.53	358 53 55.63	166.69	85.00
Fact. $T \times .9536$,	+ 45.60	+ 6.58	— 8.75	— .05	— .36
Fact. $T^2 \times .91$,	+ 0.22	0	0	+ .01	— .02
1795, May 9,	215 42 34.19	228 42 51.61	129 30 22.67	331.77	233.84

$2\,l = 71.25$
$l = 215.7095$

	Arg. 3	4	5	6	7	8	9
Table I., 1892,	320.05	298	186	38	314.2	394	246
Table II., 3^y May,	104.18	82	45	29	216.6	112	96
Table III., Day 9,	0.68	1	0	0	1.4	1	1
Table IV., 1700,	70.66	327	242	328	298.6	228	313
Fact. $T \times .9536$,	+ 0.12	— 1	0	— 1	+ 0.2	0	0
1795, May 9,	95.69	307	73	394	31.0	335	256

Longitude.	″
$P_{s.1}$	16.69
$P_{c.1}$	0.38
$P_{s.2}$	5.16
$P_{c.2}$	1.97
$P_{s.1}$ sin l	— 9.74
$P_{c.1}$ cos l	— 0.31
$P_{s.2}$ sin 2 l	+ 4.90
$P_{c.2}$ cos 2 l	+ 0.63
δv_1	24.08
δv_2	9.48
δv_3	69.05
δv_4	0.54
δv_5	0.07
δv_6	0.92
δv_7	1.32
δv_8	0.34
δv_9	0.06
Eq. Cent.	1 7 1.63
l	215 42 34.19
y	228 42 51.61
u	85 34 8.77
θ	129 30 22.67
Red. Ecliptic	52.26
Long. (Mean Eq.)	215 5 23.70
Nutation	— 15.90
Long. (True Eq.)	215 5 7.80

Radius vector.	
$R_{s.1}$	242
$R_{c.1}$	77
$R_{s.1}$ sin l	— 141
$R_{c.1}$ cos l	— 63
δr_1	234
δr_2	60
δr_3	747
Prin. term	1.4816441
log r	1.4817278

Latitude.	″
$B_{s.1}$	0.39
$B_{c.1}$	0.73
log sin u	9.998700
log sin i	8.494395
log sin β_0	8.493095
	′ ″
$B_{s.1}$ sin l	— 0.22
$B_{c.1}$ cos l	— 0.59
$\delta\beta_1$	— 0.06
$\delta\beta_2$	— 0.46
β_0	+ 1 47 0.82
Latitude	+ 1 46 59.49

TABLE I.

Epochs and Arguments for the Beginning of each Fourth Year from 1800 to 1952.

Year.	P	l	y	θ	1
1800	25	225 51 36.90	228 43 40.52	129 33 27.21	342.62
1804	24	234 35 57.56	228 44 22.73	129 36 5.97	351.95
1808	23	243 20 18.15	228 45 04.92	129 38 44.75	361.28
1812	22	252 4 38.66	228 45 47.10	129 41 23.54	370.62
1816	21	260 48 59.10	228 46 29.27	129 44 2.35	379.95
1820	20	269 33 19.46	228 47 11.42	129 46 41.18	389.28
1824	19	278 17 39.74	228 47 53.56	129 49 20.02	398.62
1828	18	287 1 59.94	228 48 35.69	129 51 58.88	7.95
1832	17	295 46 20.07	228 49 17.81	129 54 37.75	17.29
1836	16	304 30 40.12	228 49 59.92	129 57 16.64	26.62
1840	15	313 15 00.09	228 50 42.02	129 59 55.54	35.95
1844	14	321 59 19.98	228 51 24.11	130 2 34.45	45.29
1848	13	330 43 39.80	228 52 6.18	130 5 13.38	54.62
1852	12	339 27 59.54	228 52 48.24	130 7 52.33	63.96
1856	11	348 12 19.20	228 53 30.30	130 10 31.29	73.29
1860	10	356 56 38.79	228 54 12.34	130 13 10.26	82.63
1864	9	5 40 58.30	228 54 54.37	130 15 49.25	91.96
1868	8	14 25 17.73	228 55 36.39	130 18 28.26	101.30
1872	7	23 9 37.08	228 56 18.40	130 21 7.28	110.63
1876	6	31 53 56.36	228 57 0.40	130 23 46.31	119.96
1880	5	40 38 15.56	228 57 42.39	130 26 25.35	129.30
1884	4	49 22 34.68	228 58 24.36	130 29 4.42	138.63
1888	3	58 6 53.72	228 59 6.32	130 31 43.50	147.97
1892	2	66 51 12.69	228 59 48.26	130 34 22.60	157.30
1896	1	75 35 31.58	229 0 30.20	130 37 1.71	166.64
1900	0	84 19 28.87	229 1 12.09	130 39 40.75	175.97
1904	−1	93 3 47.60	229 1 54.01	130 42 19.89	185.30
1908	−2	101 48 6.26	229 2 35.92	130 44 59.04	194.64
1912	−3	110 32 24.84	229 3 17.82	130 47 38.20	203.97
1916	−4	119 16 43.35	229 3 59.71	130 50 17.38	213.31
1920	−5	128 1 1.78	229 4 41.58	130 52 56.58	222.64
1924	−6	136 45 20.13	229 5 23.44	130 55 35.80	231.98
1928	−7	145 29 38.40	229 6 5.29	130 58 15.02	241.31
1932	−8	154 13 56.60	229 6 47.14	131 0 54.26	250.65
1936	−9	162 58 14.72	229 7 28.99	131 3 33.51	259.98
1940	−10	171 42 32.77	229 8 10.80	131 6 12.77	269.32
1944	−11	180 26 50.73	229 8 52.61	131 8 52.06	278.65
1948	−12	189 11 8.62	229 9 34.41	131 11 31.35	287.99
1952	−13	197 55 26.43	229 10 16.20	131 14 10.66	297.32
		° ′ ″	″	″	
$\Delta^{(1)}_{(180)}$		1 4 35.943	5.182	19.583	1.150
Fact. T		−0.237	−0.033	+0.044	0.0
$\Delta^{(2)}_{(180)}$		−0.0012	−0.0002	+0.0002	0

TABLE I.

EPOCHS AND ARGUMENTS FOR THE BEGINNING OF EACH FOURTH YEAR FROM 1800 TO 1952 (Continued).

Year.	2	3	4	5	6	7	8	9
1800	285.66	241.09	22	137	35	333.1	92	390
1804	330.27	366.26	121	191	70	193.2	227	105
1808	374.88	91.44	220	245	104	53.2	362	221
1812	19.49	216.61	319	300	139	313.3	97	336
1816	64.10	341.78	18	354	174	173.3	232	52
1820	108.71	66.96	117	8	209	33.4	367	167
1824	153.32	192.13	216	63	244	293.4	101	283
1828	197.94	317.31	315	117	279	153.5	236	398
1832	242.55	42.48	14	171	314	13.5	371	114
1836	287.17	167.65	113	226	349	273.5	106	229
1840	331.78	292.82	212	280	384	133.6	241	345
1844	376.40	18.00	310	334	19	393.6	376	60
1848	21.02	143.17	9	388	54	253.7	111	176
1852	65.64	268.34	108	43	88	113.7	245	291
1856	110.25	393.51	207	97	123	373.8	380	6
1860	154.87	118.68	306	151	158	233.8	115	122
1864	199.49	243.86	5	206	193	93.9	250	237
1868	244.16	369.03	104	260	228	353.9	385	353
1872	288.73	94.20	203	314	263	214.0	120	68
1876	333.35	219.37	302	369	298	74.0	255	184
1880	377.98	344.54	1	23	333	334.0	390	299
1884	22.60	69.71	100	77	368	194.1	125	15
1888	67.22	194.88	199	132	3	54.1	259	130
1892	111.85	320.05	298	186	38	314.2	394	246
1896	156.47	45.22	397	240	72	174.2	129	361
1900	201.06	170.29	96	295	107	34.3	264	77
1904	245.69	295.46	195	349	142	294.3	399	192
1908	290.32	20.63	294	3	177	154.4	134	308
1912	334.94	145.80	393	58	212	14.4	269	23
1916	379.57	270.97	92	112	247	274.5	4	138
1920	24.20	396.14	191	166	282	134.5	138	254
1924	68.82	121.30	290	221	317	394.6	273	369
1928	113.45	246.47	389	275	352	254.6	8	85
1932	158.08	371.64	88	330	387	114.7	143	200
1936	202.72	96.81	187	384	22	374.7	278	316
1940	247.35	221.97	286	38	57	234.8	13	31
1944	291.98	347.14	385	92	92	94.8	148	147
1948	336.61	72.31	84	147	126	354.9	283	262
1952	381.25	197.47	182	201	162	214.9	17	378
$\Delta^{(1)}_{(180)}$	5.497	15.421	12.20	6.7	4.3	32.03	16.6	14.2
Fact. T	+ .001	0	0	0	0	0	0	0
$\Delta^{(2)}_{(180)}$	0	0	0	0	0	0	0	0

TABLE II.

REDUCTION OF THE EPOCHS AND ARGUMENTS TO THE FIRST DAY OF EACH MONTH IN A CYCLE OF FOUR YEARS.

	l	l'	y	θ	θ'	1
Year 0,	° ′ ″		″	′ ″		
Jan. 1,	0 0 0.00	0.00	0.00	0 00.00	0.00	0.00
Feb. 1,	0 11 7.50	0.16	0.89	0 3.37	— 0.01	0.20
Mar. 1,	0 21 31.94	0.32	1.72	0 6.53	— 0.01	0.38
Apr. 1,	0 32 39.44	0.48	2.61	0 9.90	— 0.02	0.58
May 1,	0 43 25.41	0.64	3.48	0 13.17	— 0.03	0.77
June 1,	0 54 32.92	0.80	4.37	0 16.54	— 0.04	0.97
July 1,	1 5 18.89	0.96	5.23	0 19.81	— 0.05	1.16
Aug. 1,	1 16 26.39	1.12	6.12	0 23.18	— 0.05	1.36
Sept. 1,	1 27 33.89	1.29	7.01	0 26.55	— 0.06	1.56
Oct. 1,	1 38 19.86	1.45	7.88	0 29.82	— 0.07	1.75
Nov. 1,	1 49 27.37	1.61	8.77	0 33.19	— 0.08	1.95
Dec. 1,	2 0 13.34	1.77	9.64	0 36.46	— 0.08	2.14
Year 1,						
Jan. 1,	2 11 20.84	1.93	10.53	0 39.83	— 0.09	2.34
Feb. 1,	2 22 28.34	2.09	11.42	0 43.20	— 0.10	2.54
Mar. 1,	2 32 31.25	2.25	12.23	0 46.25	— 0.11	2.72
Apr. 1,	2 43 38.75	2.41	13.12	0 49.62	— 0.11	2.91
May 1,	2 54 24.72	2.57	13.98	0 52.89	— 0.12	3.10
June 1,	3 5 32.22	2.73	14.87	0 56.26	— 0.13	3.30
July 1,	3 16 18.19	2.89	15.74	0 59.53	— 0.14	3.49
Aug. 1,	3 27 25.70	3.05	16.63	1 2.90	— 0.14	3.69
Sept. 1,	3 38 33.20	3.21	17.52	1 6.28	— 0.15	3.89
Oct. 1,	3 49 19.17	3.37	18.39	1 9.54	— 0.16	4.08
Nov. 1,	4 0 26.67	3.53	19.28	1 12.92	— 0.17	4.28
Dec. 1,	4 11 12.64	3.69	20.15	1 16.18	— 0.17	4.47
Year 2,						
Jan. 1,	4 22 20.15	3.85	21.04	1 19.56	— 0.18	4.67
Feb. 1,	4 33 27.65	4.01	21.93	1 22.93	— 0.19	4.87
Mar. 1,	4 43 30.55	4.17	22.74	1 25.98	— 0.20	5.05
Apr. 1,	4 54 38.06	4.33	23.63	1 29.35	— 0.20	5.24
May 1,	5 5 24.03	4.49	24.49	1 32.62	— 0.21	5.44
June 1,	5 16 31.53	4.65	25.38	1 35.99	— 0.22	5.63
July 1,	5 27 17.50	4.81	26.25	1 39.26	— 0.23	5.83
Aug. 1,	5 38 25.00	4.97	27.14	1 42.63	— 0.23	6.02
Sept. 1,	5 49 32.50	5.13	28.03	1 46.00	— 0.24	6.22
Oct. 1,	6 0 18.47	5.29	28.90	1 49.26	— 0.25	6.41
Nov. 1,	6 11 25.97	5.45	29.79	1 52.64	— 0.26	6.61
Dec. 1,	6 22 11.94	5.61	30.66	1 55.90	— 0.26	6.80
Year 3,						
Jan. 1,	6 33 19.44	5.77	31.55	1 59.27	— 0.27	7.00
Feb. 1,	6 44 26.95	5.93	32.44	2 2.64	— 0.28	7.20
Mar. 1,	6 54 29.85	6.09	33.25	2 5.69	— 0.29	7.38
Apr. 1,	7 5 37.35	6.25	34.14	2 9.06	— 0.29	7.58
May 1,	7 16 23.32	6.41	35.00	2 12.33	— 0.30	7.77
June 1,	7 27 30.82	6.57	35.80	2 15.70	— 0.31	7.97
July 1,	7 38 16.79	6.73	36.77	2 18.97	— 0.32	8.16
Aug. 1,	7 49 24.29	6.89	37.66	2 22.34	— 0.32	8.36
Sept. 1,	8 0 31.80	7.05	38.55	2 25.72	— 0.33	8.55
Oct. 1,	8 11 17.76	7.21	39.40	2 28.98	— 0.34	8.75
Nov. 1,	8 22 25.27	7.37	40.30	2 32.36	— 0.34	8.94
Dec. 1,	8 33 11.24	7.53	41.17	2 35.62	— 0.35	9.14

Columns l' and θ' interpolated to the day of the month must be multiplied by the integer, P, of Table I. (not interpolated), and the units of the product added to the hundredths of seconds of l.

TABLE II.

Reduction of the Epochs and Arguments to the First Day of each Month in a Cycle of Four Years (Continued).

	2	3	4	5	6	7	8	9
Year 0,								
Jan. 1,	0.00	0.00	0	0	0	0.0	0	0
Feb. 1,	0.95	2.66	2	1	1	5.5	3	2
Mar. 1,	1.83	5.14	4	2	1	10.7	6	5
Apr. 1,	2.78	7.80	6	3	2	16.2	8	7
May 1,	3.70	10.37	8	4	3	21.6	11	10
June 1,	4.64	13.02	10	6	4	27.1	14	12
July 1,	5.56	15.59	12	7	4	32.4	17	14
Aug. 1,	6.50	18.25	14	8	5	37.9	20	17
Sept. 1,	7.45	20.90	16	9	6	43.5	22	19
Oct. 1,	8.37	23.47	19	10	7	48.8	25	22
Nov. 1,	9.31	26.13	21	11	7	54.3	28	24
Dec. 1,	10.23	28.70	23	12	8	59.7	31	26
Year 1,								
Jan. 1,	11.18	31.36	25	14	9	65.2	34	29
Feb. 1,	12.12	34.01	27	15	9	70.7	37	31
Mar. 1,	12.98	36.41	29	16	10	75.7	39	34
Apr. 1,	13.92	39.07	31	17	11	81.3	42	36
May 1,	14.84	41.64	33	18	12	86.6	45	38
June 1,	15.79	44.29	35	19	12	92.2	48	41
July 1,	16.70	46.86	37	20	13	97.5	50	43
Aug. 1,	17.65	49.52	39	22	14	103.0	53	46
Sept. 1,	18.51	52.18	41	23	15	108.5	56	48
Oct. 1,	19.51	54.75	43	24	15	113.9	59	51
Nov. 1,	20.46	57.40	45	25	16	119.4	62	53
Dec. 1,	21.38	59.97	47	26	17	124.7	65	55
Year 2,								
Jan. 1,	22.32	62.63	50	27	17	130.2	68	58
Feb. 1,	23.27	65.29	52	28	18	135.7	70	60
Mar. 1,	24.12	67.68	54	29	19	140.7	73	62
Apr. 1,	25.07	70.34	56	30	20	146.2	76	65
May 1,	25.99	72.91	58	32	20	151.6	79	67
June 1,	26.93	75.57	60	33	21	157.1	81	70
July 1,	27.85	78.14	62	34	22	162.4	84	72
Aug. 1,	28.80	80.79	64	35	23	167.9	87	74
Sept. 1,	29.74	83.45	66	36	23	173.4	90	77
Oct. 1,	30.66	86.02	68	37	24	178.8	93	79
Nov. 1,	31.60	88.67	70	38	25	184.3	96	82
Dec. 1,	32.52	91.24	72	40	25	189.6	98	84
Year 3,								
Jan. 1,	33.47	93.90	74	41	26	195.1	101	87
Feb. 1,	34.42	96.56	76	42	27	200.7	104	89
Mar. 1,	35.27	98.96	78	43	28	205.7	107	91
Apr. 1,	36.22	101.61	80	44	28	211.2	110	94
May 1,	37.13	104.18	82	45	29	216.6	112	96
June 1,	38.08	106.84	84	46	30	222.1	115	98
July 1,	39.00	109.41	87	47	30	227.4	118	01
Aug. 1,	39.94	112.06	89	49	31	232.9	121	03
Sept. 1,	40.89	114.72	91	50	32	238.4	124	106
Oct. 1,	41.81	117.29	93	51	33	243.8	126	108
Nov. 1,	42.75	119.95	95	52	34	249.3	129	111
Dec. 1,	43.67	122.52	97	53	34	254.6	132	113

TABLE III.

Reduction from the First to Subsequent Days of any Month.

Days.	l	y	θ	1	2	3	4	5	6	7	8	9
	′ ″	″	″									
1	0 0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0.0	0	0
2	0 21.53	0.03	0.11	0.01	0.03	0.09	0	0	0	0.2	0	0
3	0 43.06	0.06	0.22	0.01	0.06	0.17	0	0	0	0.4	0	0
4	1 4.60	0.09	0.33	0.02	0.09	0.26	0	0	0	0.5	0	0
5	1 26.13	0.11	0.44	0.03	0.12	0.34	0	0	0	0.7	0	0
6	1 47.66	0.14	0.54	0.03	0.15	0.43	0	0	0	0.9	0	0
7	2 9.19	0.17	0.65	0.04	0.18	0.51	0	0	0	1.1	0	0
8	2 30.73	0.20	0.76	0.04	0.21	0.60	1	0	0	1.3	1	1
9	2 52.26	0.23	0.87	0.05	0.24	0.68	1	0	0	1.4	1	1
10	3 13.79	0.26	0.98	0.06	0.27	0.77	1	0	0	1.6	1	1
11	3 35.32	0.29	1 09	0.06	0.30	0.86	1	0	0	1.8	1	1
12	3 56.86	0.32	1.20	0.07	0.34	0.94	1	0	0	2.0	1	1
13	4 18.39	0.35	1.31	0.08	0.37	1.03	1	0	0	2.2	1	1
14	4 39.92	0.37	1.41	0.08	0.40	1.11	1	0	0	2.3	1	1
15	5 1.45	0.40	1.52	0.09	0.43	1.20	1	1	0	2.5	1	1
16	5 22.99	0.43	1.63	0.10	0.46	1.28	1	1	0	2.7	1	1
17	5 44.52	0.46	1.74	0.10	0.49	1.37	1	1	0	2.9	2	1
18	6 6.05	0.49	1.85	0.11	0.52	1.46	1	1	0	3.1	2	1
19	6 27.58	0.52	1.96	0.12	0.55	1.54	1	1	0	3.2	2	1
20	6 49.11	0.54	2.07	0.12	0.58	1.63	1	1	0	3.4	2	1
21	7 10.65	0.57	2.18	0.13	0.61	1.71	1	1	0	3.6	2	2
22	7 32.18	0.60	2.29	0.13	0.64	1.80	1	1	1	3.8	2	2
23	7 53.71	0.63	2.39	0.14	0.67	1.88	2	1	1	3.9	2	2
24	8 15.24	0.66	2.50	0.15	0.70	1.97	2	1	1	4.1	2	2
25	8 36.78	0.69	2.61	0.15	0.73	2.06	2	1	1	4.3	2	2
26	8 58.31	0.72	2.72	0.16	0.76	2.14	2	1	1	4.4	2	2
27	9 19.84	0.75	2.83	0.17	0.79	2.23	2	1	1	4.6	2	2
28	9 41.37	0.78	2.94	0.17	0.83	2.31	2	1	1	4.8	3	2
29	10 2.91	0.80	3.05	0.18	0.86	2.40	2	1	1	4.9	3	2
30	10 24.44	0.83	3.16	0.18	0.89	2.48	2	1	1	5.1	3	2
31	10 45.97	0.86	3.26	0.19	0.92	2.57	2	1	1	5.3	3	2

In January and February of 1700, 1800, and 1900, Table III. must be entered with a number of days 1 *greater* than the real day of the month.

TABLE IV.

Corrections for Past and Future Centuries.

	1600	Fact. T	Fact. T^3	1700	Fact. T	Fact. T^2	1900	Fact. T	Fact. T^2
	° ′ ″	″	″	° ′ ″	″	″	° ′ ″	″	″
l	283 1 52.88	+94.09	+1.03	141 31 19.97	+47.82	+0.24	218 27 51.97	−48.17	+0.17
y	359 24 35.91	+14.05	0	359 42 21.53	+ 6.90	0	0 17 31.57	− 6.92	0
θ	357 48 0.68	−18.59	0	358 53 55.63	− 9.17	0	1 6 13.54	+ 9.19	0
Arg. 1	333.41	−0.08	+0.01	166.69	−0.05	+0.01	233.35	+0.02	−0.10
2	170.36	−0.69	−0.08	85.00	−0.38	−0.02	315.40	+0.46	+0.06
3	141.19	+0.22	+0.04	70.66	+0.13	0.00	329.20	−0.17	0
4	255.	−2	0	327.	−1	0	74.	0	0
5	85.	−1	0	242.	0	0	158.	0	0
6	256.	−1.	0	328.	−1	0	72.	+1.	0
7	196.9	+0.5	0	298.6	+0.2	0	101.2	−0.4	0
8	55.	0	0	228.	0	0	172.	0	0
9	227.	0	0	313.	0	0	87.		0

Table.	V.								VI.		VII.	
Arg.	1								2		3	
	$P_{s.1}$	Diff.	$P_{c.1}$	Diff.	$P_{s.2}$	$P_{c.2}$	δv_1	Diff.	δv_2	Diff.	δv_3	Diff.
	″	″	″	″	″	″	″	″	″	″	″	″
0	0.38		13.22		0.54	2.84	13.85		19.00		35.00	
1	0.36	0.02	13.49	0.27	0.54	2.92	13.33	0.52	19.29	0.29	35.54	0.54
2	0.35	0.01	13.76	0.27	0.53	3.00	12.80	0.53	19.57	0.28	36.07	0.53
3	0.34	0.01	14.03	0.27	0.53	3.08	12.28	0.52	19.86	0.29	36.61	0.54
4	0.33	0.01	14.30	0.27	0.53	3.16	11.76	0.52	20.14	0.28	37.14	0.53
5	0.33	0.00	14.57	0.27	0.54	3.25	11.25	0.51	20.43	0.29	37.68	0.54
6	0.33	0.00	14.84	0.27	0.54	3.33	10.74	0.51	20.72	0.29	38.21	0.53
7	0.34	0.01	15.11	0.27	0.55	3.41	10.24	0.50	21.00	0.28	38.75	0.54
8	0.34	0.00	15.38	0.27	0.56	3.50	9.74	0.50	21.29	0.29	39.28	0.53
9	0.36	0.02	15.66	0.28	0.58	3.58	9.25	0.49	21.57	0.28	39.81	0.53
10	0.38	0.02	15.93	0.27	0.59	3.66	8.76	0.49	21.85	0.28	40.34	0.53
11	0.40	0.02	16.21	0.28	0.61	3.74	8.29	0.47	22.14	0.29	40.87	0.53
12	0.43	0.03	16.49	0.28	0.64	3.83	7.83	0.46	22.42	0.28	41.39	0.52
13	0.46	0.03	16.76	0.27	0.66	3.91	7.38	0.45	22.70	0.28	41.92	0.53
14	0.50	0.04	17.04	0.28	0.69	3.99	6.94	0.44	22.98	0.28	42.44	0.52
15	0.55	0.05	17.32	0.28	0.72	4.07	6.51	0.43	23.26	0.28	42.97	0.53
16	0.60	0.05	17.60	0.28	0.76	4.15	6.09	0.42	23.54	0.28	43.49	0.52
17	0.66	0.06	17.88	0.28	0.80	4.23	5.69	0.40	23.81	0.27	44.01	0.52
18	0.73	0.07	18.17	0.29	0.84	4.31	5.30	0.39	24.09	0.28	44.53	0.52
19	0.81	0.08	18.45	0.28	0.88	4.39	4.93	0.37	24.37	0.28	45.04	0.51
20	0.89	0.08	18.74	0.29	0.93	4.46	4.57	0.36	24.64	0.27	45.55	0.51
21	0.98	0.09	19.02	0.28	0.97	4.54	4.22	0.35	24.91	0.27	46.06	0.51
22	1.08	0.10	19.31	0.29	1.03	4.61	3.89	0.33	25.18	0.27	46.57	0.51
23	1.19	0.11	19.59	0.28	1.08	4.68	3.58	0.31	25.45	0.27	47.07	0.50
24	1.30	0.11	19.88	0.29	1.14	4.76	3.28	0.30	25.72	0.27	47.57	0.50
25	1.43	0.13	20.16	0.28	1.20	4.83	3.00	0.28	25.99	0.27	48.07	0.50
26	1.56	0.13	20.44	0.28	1.27	4.89	2.73	0.27	26.25	0.26	48.56	0.49
27	1.70	0.14	20.73	0.29	1.34	4.96	2.48	0.25	26.52	0.27	49.05	0.49
28	1.86	0.16	21.01	0.28	1.41	5.02	2.25	0.23	26.78	0.26	49.54	0.49
29	2.02	0.16	21.29	0.28	1.49	5.08	2.03	0.22	27.04	0.26	50.02	0.48
30	2.19	0.17	21.57	0.28	1.56	5.14	1.82	0.21	27.30	0.26	50.50	0.48
31	2.38	0.19	21.84	0.27	1.64	5.20	1.63	0.19	27.55	0.25	50.97	0.47
32	2.57	0.19	22.11	0.27	1.73	5.25	1.46	0.17	27.81	0.26	51.44	0.47
33	2.77	0.20	22.38	0.27	1.81	5.30	1.30	0.16	28.06	0.25	51.91	0.47
34	2.98	0.21	22.65	0.27	1.90	5.34	1.16	0.14	28.31	0.25	52.38	0.47
35	3.21	0.23	22.91	0.26	1.99	5.38	1.04	0.12	28.56	0.25	52.84	0.46
36	3.44	0.23	23.17	0.26	2.09	5.42	0.93	0.11	28.80	0.24	53.29	0.45
37	3.68	0.24	23.42	0.25	2.18	5.45	0.84	0.09	29.04	0.24	53.74	0.45
38	3.93	0.25	23.67	0.25	2.28	5.48	0.76	0.08	29.28	0.24	54.18	0.44
39	4.19	0.26	23.92	0.25	2.38	5.51	0.69	0.07	29.52	0.24	54.63	0.45
40	4.46	0.27	24.16	0.24	2.48	5.53	0.64	0.05	29.76	0.24	55.07	0.44
41	4.74	0.28	24.39	0.23	2.58	5.54	0.60	0.04	29.99	0.23	55.50	0.43
42	5.03	0.29	24.62	0.23	2.69	5.56	0.58	0.02	30.22	0.23	55.92	0.42
43	5.33	0.30	24.84	0.22	2.79	5.56	0.57	0.01	30.45	0.23	56.34	0.42
44	5.64	0.31	25.05	0.21	2.90	5.56	0.57	0.00	30.68	0.23	56.76	0.42
45	5.95	0.31	25.25	0.20	3.00	5.56	0.59	0.02	30.90	0.22	57.17	0.41
46	6.28	0.33	25.45	0.20	3.11	5.55	0.61	0.02	31.12	0.22	57.57	0.40
47	6.61	0.33	25.64	0.19	3.21	5.54	0.65	0.04	31.34	0.22	57.97	0.40
48	6.94	0.33	25.82	0.18	3.32	5.53	0.70	0.05	31.55	0.21	58.36	0.39
49	7.29	0.35	25.99	0.17	3.42	5.51	0.77	0.07	31.76	0.21	58.75	0.39
50	7.64	0.35	26.16	0.17	3.52	5.48	0.85	0.08	31.97	0.21	59.14	0.39

Table.	V.								VI.		VII.	
Arg.	1								2		3	
	$P_{s.1}$	Diff.	$P_{c.1}$	Diff.	$P_{s.2}$	$P_{c.2}$	δv_1	Diff.	δv_2	Diff.	δv_3	Diff.
	″	″	″	″	″	″	″	″	″	″	″	″
50	7.64		26.16		3.52	5.48	0.85		31.97		59.14	
51	8.00	0.36	26.31	0.15	3.63	5.45	0.94	0.09	32.17	0.20	59.52	0.38
52	8.36	0.36	26.45	0.14	3.73	5.41	1.03	0.09	32.38	0.21	59.89	0.37
53	8.73	0.37	26.59	0.14	3.83	5.37	1.14	0.11	32.58	0.20	60.25	0.36
54	9.11	0.38	26.71	0.12	3.92	5.33	1.26	0.12	32.77	0.19	60.61	0.36
55	9.49	0.38	26.82	0.11	4.02	5.28	1.39	0.13	32.96	0.19	60.96	0.35
56	9.87	0.38	26.93	0.11	4.11	5.23	1.53	0.14	33.15	0.19	61.30	0.34
57	10.26	0.39	27.02	0.09	4.20	5.17	1.67	0.14	33.34	0.19	61.63	0.33
58	10.65	0.39	27.10	0.08	4.29	5.11	1.83	0.16	33.52	0.18	61.96	0.33
59	11.05	0.40	27.17	0.07	4.38	5.04	2.00	0.17	33.70	0.18	62.29	0.33
60	11.45	0.40	27.23	0.06	4.46	4.97	2.18	0.18	33.87	0.17	62.61	0.32
61	11.85	0.40	27.28	0.05	4.55	4.90	2.37	0.19	34.04	0.17	62.91	0.30
62	12.25	0.40	27.32	0.04	4.62	4.82	2.56	0.19	34.21	0.17	63.22	0.31
63	12.65	0.40	27.34	0.02	4.70	4.74	2.76	0.20	34.37	0.16	63.52	0.30
64	13.06	0.41	27.36	0.02	4.76	4.65	2.97	0.21	34.53	0.16	63.81	0.29
65	13.47	0.41	27.36	0.00	4.83	4.57	3.18	0.21	34.69	0.16	64.10	0.29
66	13.88	0.41	27.35	0.01	4.89	4.48	3.40	0.22	34.84	0.15	64.38	0.28
67	14.29	0.41	27.33	0.02	4.94	4.39	3.63	0.23	34.99	0.15	64.65	0.27
68	14.70	0.41	27.29	0.04	5.00	4.29	3.87	0.24	35.14	0.15	64.91	0.26
69	15.10	0.40	27.25	0.04	5.04	4.20	4.11	0.24	35.28	0.14	65.17	0.26
70	15.51	0.41	27.19	0.06	5.09	4.10	4.36	0.25	35.42	0.14	65.41	0.24
71	15.92	0.41	27.12	0.07	5.13	3.99	4.61	0.25	35.55	0.13	65.65	0.24
72	16.32	0.40	27.04	0.08	5.16	3.89	4.86	0.25	35.68	0.13	65.88	0.23
73	16.72	0.40	26.95	0.09	5.19	3.79	5.13	0.27	35.81	0.13	66.10	0.22
74	17.12	0.40	26.84	0.11	5.22	3.69	5.39	0.26	35.93	0.12	66.32	0.22
75	17.51	0.39	26.72	0.12	5.24	3.58	5.66	0.27	36.04	0.11	66.53	0.21
76	17.90	0.39	26.59	0.13	5.25	3.48	5.94	0.28	36.16	0.12	66.72	0.19
77	18.29	0.39	26.45	0.14	5.26	3.37	6.21	0.27	36.27	0.11	66.92	0.20
78	18.67	0.38	26.30	0.15	5.27	3.27	6.50	0.29	36.37	0.10	67.11	0.19
79	19.05	0.38	26.14	0.16	5.27	3.16	6.78	0.28	36.47	0.10	67.28	0.17
80	19.42	0.37	25.96	0.18	5.27	3.05	7.07	0.29	36.57	0.10	67.45	0.17
81	19.78	0.36	25.78	0.18	5.26	2.95	7.36	0.29	36.66	0.09	67.61	0.16
82	20.14	0.36	25.58	0.20	5.25	2.85	7.65	0.29	36.75	0.09	67.76	0.15
83	20.49	0.35	25.37	0.21	5.23	2.74	7.94	0.29	36.83	0.08	67.91	0.15
84	20.84	0.35	25.15	0.22	5.21	2.64	8.24	0.30	36.91	0.08	68.05	0.14
85	21.18	0.34	24.93	0.22	5.18	2.54	8.54	0.30	36.98	0.07	68.18	0.13
86	21.51	0.33	24.69	0.24	5.15	2.45	8.83	0.29	37.05	0.07	68.30	0.12
87	21.83	0.32	24.44	0.25	5.11	2.35	9.13	0.30	37.12	0.07	68.41	0.11
88	22.14	0.31	24.18	0.26	5.07	2.25	9.43	0.30	37.18	0.06	68.52	0.11
89	22.45	0.31	23.91	0.27	5.02	2.16	9.73	0.30	37.24	0.06	68.61	0.09
90	22.74	0.29	23.64	0.27	4.97	2.07	10.02	0.29	37.29	0.05	68.70	0.09
91	23.02	0.28	23.35	0.29	4.92	1.98	10.32	0.30	37.34	0.05	68.78	0.08
92	23.30	0.28	23.06	0.29	4.86	1.90	10.62	0.30	37.38	0.04	68.85	0.07
93	23.56	0.26	22.75	0.31	4.80	1.82	10.92	0.30	37.42	0.04	68.91	0.06
94	23.81	0.25	22.44	0.31	4.74	1.74	11.21	0.29	37.45	0.03	68.97	0.06
95	24.05	0.24	22.12	0.32	4.67	1.66	11.51	0.30	37.48	0.03	69.02	0.05
96	24.28	0.23	21.80	0.32	4.60	1.59	11.80	0.29	37.51	0.03	69.06	0.04
97	24.50	0.22	21.47	0.33	4.53	1.53	12.10	0.30	37.53	0.02	69.09	0.03
98	24.71	0.21	21.13	0.34	4.45	1.46	12.38	0.28	37.55	0.02	69.11	0.02
99	24.91	0.20	20.78	0.35	4.37	1.40	12.67	0.29	37.56	0.01	69.12	0.01
100	25.10	0.19	20.43	0.35	4.28	1.35	12.96	0.29	37.56	0.00	69.12	0.00

Table.	V.								VI.		VII.	
Arg.	1								2		3	
	$P_{s.1}$	Diff.	$P_{c.1}$	Diff.	$P_{s.1}$	$P_{c.2}$	δv_1	Diff.	δv_2	Diff.	δv_3	Diff.
	″	″	″	″	″	″	″	″	″	″	″	″
100	25.10	0.16	20.43	0.35	4.28	1.35	12.96	0.28	37.56	0.01	69.12	0.00
101	25.26	0.16	20.08	0.36	4.20	1.30	13.24	0.28	37.57	0.01	69.12	0.01
102	25.42	0.15	19.72	0.37	4.11	1.25	13.52	0.27	37.56	0.00	69.11	0.02
103	25.57	0.13	19.35	0.37	4.02	1.21	13.79	0.29	37.56	0.02	69.09	0.03
104	25.70	0.12	18.98	0.37	3.93	1.17	14.08	0.26	37.54	0.01	69.06	0.04
105	25.82	0.10	18.61	0.38	3.84	1.14	14.34	0.26	37.53	0.02	69.02	0.05
106	25.92	0.10	18.23	0.37	3.75	1.11	14.60	0.27	37.51	0.03	68.97	0.06
107	26.02	0.08	17.86	0.39	3.65	1.09	14.87	0.26	37.48	0.03	68.91	0.06
108	26.10	0.06	17.47	0.38	3.56	1.07	15.13	0.25	37.45	0.03	68.85	0.07
109	26.16	0.06	17.09	0.38	3.46	1.05	15.38	0.25	37.42	0.04	68.78	0.08
110	26.22	0.04	16.71	0.39	3.36	1.04	15.63	0.24	37.38	0.05	68.70	0.08
111	26.26	0.02	16.32	0.28	3.27	1.04	15.87	0.24	37.33	0.05	68.62	0.10
112	26.28	0.02	15.94	0.38	3.17	1.04	16.11	0.23	37.28	0.05	68.52	0.11
113	26.30	0.01	15.56	0.39	3.07	1.04	16.34	0.23	37.23	0.06	68.41	0.11
114	26.29	0.01	15.17	0.38	2.98	1.06	16.57	0.23	37.17	0.06	68.30	0.12
115	26.28	0.03	14.79	0.38	2.88	1.07	16.80	0.22	37.11	0.06	68.18	0.13
116	26.25	0.05	14.41	0.38	2.78	1.09	17.02	0.22	37.05	0.07	68.05	0.14
117	26.20	0.05	14.03	0.38	2.69	1.11	17.24	0.20	36.98	0.08	67.91	0.15
118	26.15	0.07	13.65	0.38	2.60	1.14	17.44	0.21	36.90	0.08	67.76	0.15
119	26.08	0.08	13.27	0.37	2.51	1.18	17.65	0.19	36.82	0.08	67.61	0.16
120	26.00	0.10	12.90	0.37	2.42	1.21	17.84	0.19	36.74	0.09	67.45	0.17
121	25.90	0.11	12.53	0.36	2.34	1.26	18.03	0.19	36.65	0.10	67.28	0.17
122	25.79	0.12	12.17	0.36	2.26	1.30	18.22	0.18	36.55	0.09	67.11	0.19
123	25.67	0.13	11.81	0.36	2.18	1.35	18.40	0.17	36.46	0.11	66.92	0.19
124	25.54	0.14	11.45	0.35	2.10	1.41	18.57	0.17	36.35	0.11	66.73	0.20
125	25.40	0.16	11.10	0.34	2.03	1.46	18.74	0.15	36.24	0.11	66.53	0.21
126	25.24	0.17	10.76	0.34	1.95	1.52	18.89	0.16	36.13	0.11	66.32	0.22
127	25.07	0.18	10.42	0.33	1.89	1.59	19.05	0.14	36.02	0.12	66.10	0.22
128	24.89	0.19	10.09	0.32	1.82	1.66	19.19	0.14	35.90	0.13	65.88	0.23
129	24.70	0.21	9.77	0.32	1.76	1.73	19.33	0.13	35.77	0.12	65.65	0.24
130	24.49	0.21	9.45	0.31	1.70	1.80	19.46	0.13	35.65	0.14	65.41	0.24
131	24.28	0.23	9.14	0.30	1.65	1.88	19.59	0.11	35.51	0.13	65.17	0.26
132	24.05	0.23	8.84	0.29	1.60	1.96	19.70	0.12	35.38	0.14	64.91	0.26
133	23.82	0.25	8.55	0.28	1.55	2.04	19.82	0.10	35.24	0.15	64.65	0.27
134	23.57	0.26	8.27	0.27	1.51	2.12	19.92	0.10	35.09	0.15	64.38	0.28
135	23.31	0.27	8.00	0.27	1.47	2.21	20.02	0.09	34.94	0.15	64.10	0.29
136	23.04	0.27	7.73	0.25	1.44	2.29	20.11	0.08	34.79	0.16	63.81	0.29
137	22.77	0.28	7.48	0.25	1.41	2.38	20.19	0.08	34.63	0.16	63.52	0.30
138	22.49	0.30	7.23	0.23	1.39	2.47	20.27	0.07	34.47	0.16	63.22	0.31
139	22.19	0.30	7.00	0.23	1.37	2.56	20.34	0.06	34.31	0.17	62.91	0.30
140	21.89	0.31	6.77	0.21	1.36	2.65	20.40	0.06	34.14	0.17	62.61	0.32
141	21.58	0.31	6.56	0.20	1.35	2.74	20.46	0.04	33.97	0.18	62.29	0.33
142	21.27	0.32	6.36	0.19	1.34	2.83	20.50	0.04	33.79	0.18	61.96	0.33
143	20.95	0.32	6.17	0.18	1.34	2.92	20.54	0.04	33.61	0.18	61.63	0.33
144	20.63	0.34	5.99	0.17	1.35	3.01	20.58	0.02	33.43	0.19	61.30	0.34
145	20.29	0.33	5.82	0.15	1.35	3.10	20.60	0.03	33.24	0.19	60.96	0.35
146	19.96	0.35	5.67	0.14	1.37	3.18	20.63	0.01	33.05	0.20	60.61	0.36
147	19.61	0.35	5.53	0.13	1.39	3.27	20.64	0.01	32.85	0.19	60.25	0.36
148	19.26	0.35	5.40	0.12	1.41	3.36	20.65	0.00	32.66	0.21	59.89	0.37
149	18.91	0.35	5.28	0.11	1.44	3.44	20.65	0.00	32.45	0.20	59.52	0.38
150	18.56		5.17		1.47	3.52	20.65		32.25		59.14	

Table.	V.								VI.		VII.	
Arg.	1								2		3	
	$P_{s.1}$	Diff.	$P_{c.1}$	Diff.	$P_{s.2}$	$P_{c.2}$	δv_1	Diff.	δv_2	Diff.	δv_3	Diff.
	"	"	"	"	"	"	"	"	"	"	"	"
150	18.56		5.17		1.47	3.52	20.62		32.25		59.14	
151	18.20	0.36	5.08	0.09	1.50	3.60	20.64	0.01	32.04	0.21	58.75	0.39
152	17.84	0.36	5.00	0.08	1.54	3.68	20.62	0.02	31.83	0.21	58.36	0.39
153	17.47	0.37	4.93	0.07	1.59	3.76	20.59	0.03	31.62	0.21	57.97	0.39
154	17.10	0.37	4.87	0.06	1.63	3.83	20.56	0.03	31.40	0.22	57.57	0.40
155	16.74	0.36	4.83	0.04	1.69	3.90	20.52	0.04	31.18	0.22	57.17	0.40
156	16.37	0.37	4.80	0.03	1.74	3.97	20.48	0.04	30.95	0.23	56.76	0.41
157	16.00	0.37	4.79	0.01	1.80	4.03	20.43	0.05	30.73	0.22	56.34	0.42
158	15.64	0.36	4.78	0.01	1.85	4.09	20.37	0.06	30.50	0.23	55.92	0.42
159	15.27	0.37	4.79	0.01	1.92	4.15	20.31	0.06	30.26	0.24	55.50	0.42
160	14.90	0.37	4.82	0.03	1.98	4.21	20.24	0.07	30.03	0.23	55.06	0.44
161	14.54	0.36	4.85	0.03	2.05	4.26	20.16	0.08	29.79	0.24	54.63	0.43
162	14.18	0.36	4.90	0.05	2.12	4.30	20.08	0.08	29.55	0.24	54.18	0.45
163	13.82	0.36	4.97	0.07	2.20	4.35	19.99	0.09	29.31	0.24	53.74	0.44
164	13.46	0.36	5.04	0.07	2.27	4.39	19.90	0.09	29.06	0.25	53.29	0.45
165	13.11	0.35	5.13	0.09	2.35	4.42	19.80	0.10	28.81	0.25	52.84	0.45
166	12.76	0.35	5.23	0.10	2.43	4.45	19.70	0.10	28.56	0.25	52.38	0.46
167	12.42	0.34	5.34	0.11	2.51	4.48	19.59	0.11	28.30	0.26	51.91	0.47
168	12.08	0.34	5.46	0.12	2.59	4.50	19.48	0.11	28.04	0.26	51.44	0.47
169	11.74	0.34	5.60	0.14	2.67	4.52	19.36	0.12	27.79	0.25	50.97	0.47
170	11.41	0.33	5.74	0.14	2.75	4.53	19.24	0.12	27.52	0.27	50.50	0.47
171	11.09	0.32	5.90	0.16	2.83	4.54	19.11	0.13	27.26	0.26	50.02	0.48
172	10.77	0.32	6.07	0.17	2.92	4.54	18.98	0.13	27.00	0.26	49.54	0.48
173	10.46	0.31	6.25	0.18	3.00	4.54	18.84	0.14	26.73	0.27	49.05	0.49
174	10.16	0.30	6.44	0.19	3.08	4.53	18.70	0.14	26.46	0.27	48.56	0.49
175	9.87	0.29	6.65	0.21	3.16	4.53	18.55	0.15	26.19	0.27	48.07	0.49
176	9.58	0.29	6.86	0.21	3.25	4.51	18.40	0.15	25.92	0.27	47.57	0.50
177	9.31	0.27	7.09	0.23	3.33	4.49	18.24	0.16	25.64	0.28	47.07	0.50
178	9.04	0.27	7.32	0.23	3.41	4.47	18.09	0.15	25.37	0.27	46.57	0.50
179	8.78	0.26	7.56	0.24	3.49	4.44	17.92	0.17	25.09	0.28	46.06	0.51
180	8.53	0.25	7.82	0.26	3.57	4.41	17.76	0.16	24.81	0.28	45.54	0.52
181	8.29	0.24	8.08	0.26	3.64	4.38	17.59	0.17	24.52	0.29	45.03	0.51
182	8.06	0.23	8.35	0.27	3.71	4.34	17.41	0.18	24.24	0.28	44.52	0.51
183	7.84	0.22	8.62	0.27	3.79	4.30	17.24	0.17	23.96	0.28	44.01	0.51
184	7.63	0.21	8.91	0.29	3.85	4.25	17.06	0.18	23.67	0.29	43.49	0.52
185	7.43	0.20	9.20	0.29	3.92	4.20	16.88	0.18	23.39	0.28	42.97	0.52
186	7.24	0.19	9.49	0.29	3.98	4.14	16.70	0.18	23.10	0.29	42.44	0.53
187	7.06	0.18	9.80	0.31	4.04	4.09	16.51	0.19	22.81	0.29	41.92	0.52
188	6.90	0.16	10.11	0.31	4.10	4.03	16.32	0.19	22.52	0.29	41.39	0.53
189	6.75	0.15	10.42	0.31	4.15	3.96	16.13	0.19	22.23	0.29	40.87	0.52
190	6.61	0.14	10.75	0.33	4.20	3.90	15.94	0.19	21.94	0.29	40.34	0.53
191	6.48	0.13	11.07	0.32	4.25	3.83	15.75	0.19	21.65	0.29	39.81	0.53
192	6.36	0.12	11.40	0.33	4.29	3.76	15.55	0.20	21.36	0.29	39.28	0.53
193	6.26	0.10	11.74	0.34	4.33	3.69	15.36	0.19	21.06	0.30	38.75	0.53
194	6.17	0.09	12.08	0.34	4.36	3.61	15.16	0.20	20.77	0.29	38.21	0.54
195	6.10	0.07	12.42	0.34	4.39	3.54	14.96	0.20	20.47	0.30	37.68	0.53
196	6.03	0.07	12.76	0.34	4.42	3.46	14.76	0.20	20.18	0.29	37.14	0.54
197	5.98	0.05	13.11	0.35	4.44	3.38	14.56	0.20	19.89	0.29	36.61	0.53
198	5.94	0.04	13.46	0.35	4.46	3.30	14.36	0.20	19.59	0.30	36.07	0.54
199	5.92	0.02	13.80	0.34	4.48	3.22	14.16	0.20	19.30	0.29	35.54	0.53
200	5.91	0.01	14.16	0.36	4.49	3.13	13.96	0.20	19.00	0.30	35.00	0.54

Table.	V.								VI.		VII.	
Arg.	1								2		3	
	$P_{s.1}$	Diff.	$P_{c.1}$	Diff.	$P_{s.2}$	$P_{c.2}$	δv_1	Diff.	δv_2	Diff.	δv_3	Diff.
	″	″	″	″	″	″	″	″	″	″	″	″
200	5.91		14.16		4.49	3.13	13.96		19.00		35.00	
201	5.91	0.00	14.51	0.35	4.49	3.05	13.76	0.20	18.70	0.30	34.46	0.54
202	5.92	0.01	14.86	0.35	4.49	2.97	13.56	0.20	18.41	0.29	33.93	0.53
203	5.95	0.03	15.21	0.35	4.49	2.88	13.36	0.20	18.11	0.30	33.39	0.54
204	6.00	0.05	15.55	0.34	4.48	2.80	13.16	0.20	17.82	0.29	32.86	0.53
205	6.06	0.06	15.90	0.35	4.47	2.72	12.97	0.19	17.53	0.29	32.32	0.54
206	6.12	0.06	16.25	0.35	4.45	2.64	12.77	0.20	17.23	0.30	31.79	0.53
207	6.21	0.09	16.59	0.34	4.43	2.56	12.57	0.20	16.94	0.29	31.25	0.54
208	6.30	0.09	16.93	0.34	4.41	2.48	12.38	0.19	16.64	0.30	30.72	0.53
209	6.41	0.11	17.27	0.34	4.38	2.41	12.19	0.19	16.35	0.29	30.19	0.53
210	6.53	0.12	17.60	0.33	4.34	2.33	12.00	0.19	16.06	0.29	29.66	0.53
211	6.65	0.12	17.93	0.33	4.31	2.26	11.81	0.19	15.77	0.29	29.13	0.53
212	6.80	0.15	18.26	0.33	4.27	2.19	11.62	0.19	15.48	0.29	28.61	0.52
213	6.96	0.16	18.57	0.31	4.22	2.13	11.43	0.19	15.19	0.29	28.08	0.53
214	7.14	0.18	18.89	0.32	4.17	2.06	11.25	0.18	14.90	0.29	27.56	0.52
215	7.32	0.18	19.20	0.31	4.12	2.00	11.07	0.18	14.61	0.29	27.03	0.53
216	7.51	0.19	19.50	0.30	4.07	1.94	10.89	0.18	14.33	0.28	26.51	0.52
217	7.72	0.21	19.79	0.29	4.01	1.88	10.72	0.17	14.04	0.29	25.99	0.52
218	7.94	0.22	20.08	0.29	3.95	1.83	10.55	0.17	13.76	0.28	25.48	0.51
219	8.16	0.22	20.36	0.28	3.88	1.78	10.38	0.17	13.48	0.28	24.96	0.52
220	8.40	0.24	20.63	0.27	3.82	1.73	10.22	0.16	13.19	0.29	24.45	0.51
221	8.65	0.25	20.90	0.27	3.75	1.69	10.06	0.16	12.91	0.28	23.94	0.51
222	8.91	0.26	21.15	0.25	3.68	1.65	9.90	0.16	12.63	0.28	23.43	0.51
223	9.18	0.27	21.40	0.25	3.60	1.62	9.74	0.16	12.36	0.27	22.93	0.50
224	9.45	0.27	21.64	0.24	3.53	1.59	9.59	0.15	12.08	0.28	22.43	0.50
225	9.74	0.29	21.87	0.23	3.45	1.56	9.44	0.15	11.81	0.27	21.93	0.50
226	10.04	0.30	22.08	0.21	3.37	1.54	9.30	0.14	11.54	0.27	21.44	0.49
227	10.34	0.30	22.29	0.21	3.29	1.52	9.16	0.14	11.27	0.27	20.95	0.49
228	10.65	0.31	22.49	0.20	3.22	1.50	9.03	0.13	11.00	0.27	20.46	0.49
229	10.97	0.32	22.67	0.18	3.14	1.49	8.90	0.13	10.74	0.26	19.98	0.48
230	11.30	0.33	22.85	0.18	3.06	1.49	8.78	0.12	10.48	0.26	19.50	0.48
231	11.63	0.33	23.01	0.16	2.97	1.49	8.66	0.12	10.21	0.27	19.03	0.47
232	11.97	0.34	23.16	0.15	2.89	1.49	8.54	0.12	9.96	0.25	18.56	0.47
233	12.32	0.35	23.30	0.14	2.81	1.50	8.44	0.10	9.70	0.26	18.09	0.47
234	12.67	0.35	23.42	0.12	2.73	1.51	8.33	0.11	9.44	0.26	17.62	0.47
235	13.03	0.36	23.54	0.12	2.65	1.53	8.24	0.09	9.19	0.25	17.16	0.46
236	13.39	0.36	23.64	0.10	2.57	1.55	8.14	0.10	8.94	0.25	16.71	0.45
237	13.76	0.37	23.73	0.09	2.49	1.58	8.06	0.08	8.69	0.25	16.26	0.45
238	14.12	0.36	23.81	0.08	2.42	1.60	7.97	0.09	8.45	0.24	15.82	0.44
239	14.50	0.38	23.87	0.06	2.34	1.64	7.90	0.07	8.21	0.24	15.37	0.45
240	14.87	0.37	23.93	0.06	2.27	1.68	7.83	0.07	7.97	0.24	14.94	0.43
241	15.25	0.38	23.96	0.03	2.20	1.72	7.77	0.06	7.74	0.23	14.50	0.44
242	15.63	0.38	23.99	0.03	2.13	1.76	7.71	0.06	7.50	0.24	14.08	0.42
243	16.01	0.38	24.00	0.01	2.06	1.81	7.66	0.05	7.27	0.23	13.66	0.42
244	16.39	0.38	24.00	0.00	2.00	1.87	7.61	0.05	7.05	0.22	13.24	0.42
245	16.77	0.38	23.99	0.01	1.93	1.92	7.57	0.04	6.82	0.23	12.83	0.41
246	17.16	0.39	23.96	0.03	1.88	1.98	7.54	0.03	6.60	0.22	12.43	0.40
247	17.54	0.38	23.92	0.04	1.82	2.04	7.52	0.02	6.38	0.22	12.03	0.40
248	17.92	0.38	23.86	0.06	1.77	2.11	7.50	0.02	6.17	0.21	11.64	0.39
249	18.30	0.38	23.79	0.07	1.72	2.18	7.48	0.02	5.96	0.21	11.25	0.39
250	18.67	0.37	23.71	0.08	1.67	2.25	7.48	0.00	5.75	0.21	10.86	0.39

Table.	V.								VI.		VII.	
Arg.	1								2		3	
	$P_{s.1}$	Diff.	$P_{c.1}$	Diff.	$P_{s.2}$	$P_{c.2}$	δv_1	Diff.	δv_2	Diff.	δv_3	Diff.
	″	″	″	″	″	″	″	″	″	″	″	″
250	18.67		23.71		1.67	2.25	7.48		5.75		10.86	
251	19.05	0.38	23.62	0.09	1.63	2.32	7.47	0.01	5.55	0.20	10.48	0.38
252	19.42	0.37	23.51	0.11	1.59	2.40	7.48	0.01	5.34	0.21	10.11	0.37
253	19.78	0.36	23.39	0.12	1.55	2.48	7.50	0.02	5.15	0.19	9.75	0.36
254	20.15	0.37	23.26	0.13	1.52	2.56	7.52	0.02	4.95	0.20	9.39	0.36
255	20.51	0.36	23.11	0.15	1.50	2.64	7.54	0.02	4.76	0.19	9.04	0.35
256	20.86	0.35	22.96	0.15	1.48	2.72	7.58	0.04	4.57	0.19	8.70	0.34
257	21.21	0.35	22.78	0.18	1.46	2.81	7.61	0.03	4.39	0.18	8.37	0.33
258	21.55	0.34	22.60	0.18	1.44	2.90	7.66	0.05	4.21	0.18	8.04	0.33
259	21.89	0.34	22.41	0.19	1.43	2.98	7.71	0.05	4.03	0.18	7.71	0.33
260	22.22	0.33	22.21	0.20	1.43	3.07	7.77	0.06	3.86	0.17	7.39	0.32
261	22.55	0.33	21.99	0.22	1.43	3.16	7.84	0.07	3.69	0.17	7.09	0.30
262	22.86	0.31	21.76	0.23	1.43	3.25	7.91	0.07	3.53	0.16	6.78	0.31
263	23.17	0.31	21.52	0.24	1.44	3.33	7.99	0.08	3.37	0.16	6.48	0.30
264	23.47	0.30	21.27	0.25	1.46	3.42	8.08	0.09	3.21	0.16	6.19	0.29
265	23.76	0.29	21.01	0.26	1.47	3.51	8.17	0.09	3.06	0.15	5.90	0.29
266	24.04	0.28	20.74	0.27	1.50	3.59	8.28	0.11	2.91	0.15	5.62	0.28
267	24.32	0.28	20.46	0.28	1.52	3.68	8.38	0.10	2.76	0.15	5.35	0.27
268	24.58	0.26	20.17	0.29	1.56	3.76	8.50	0.12	2.62	0.14	5.09	0.26
269	24.83	0.25	19.87	0.30	1.59	3.85	8.62	0.12	2.49	0.13	4.83	0.26
270	25.08	0.25	19.57	0.30	1.63	3.93	8.74	0.12	2.35	0.14	4.59	0.24
271	25.31	0.23	19.25	0.32	1.68	4.01	8.88	0.14	2.23	0.12	4.35	0.24
272	25.53	0.22	18.93	0.32	1.72	4.08	9.02	0.14	2.10	0.13	4.12	0.23
273	25.74	0.21	18.59	0.34	1.78	4.16	9.17	0.15	1.98	0.12	3.90	0.22
274	25.93	0.19	18.26	0.33	1.83	4.23	9.32	0.15	1.87	0.11	3.68	0.22
275	26.12	0.19	17.91	0.35	1.89	4.30	9.48	0.16	1.76	0.11	3.47	0.21
276	26.29	0.17	17.56	0.35	1.96	4.36	9.65	0.17	1.65	0.11	3.27	0.20
277	26.46	0.17	17.20	0.36	2.02	4.43	9.82	0.17	1.54	0.11	3.08	0.19
278	26.60	0.14	16.84	0.36	2.09	4.49	10.00	0.18	1.45	0.09	2.89	0.19
279	26.74	0.14	16.47	0.37	2.16	4.55	10.19	0.19	1.35	0.10	2.72	0.17
280	26.87	0.13	16.09	0.38	2.24	4.60	10.38	0.19	1.26	0.09	2.55	0.17
281	26.98	0.11	15.71	0.38	2.32	4.65	10.57	0.19	1.18	0.08	2.39	0.16
282	27.07	0.09	15.33	0.38	2.40	4.69	10.78	0.21	1.10	0.08	2.24	0.15
283	27.16	0.09	14.94	0.39	2.48	4.73	10.98	0.20	1.02	0.08	2.09	0.15
284	27.23	0.07	14.55	0.39	2.57	4.77	11.20	0.22	0.95	0.07	1.95	0.14
285	27.29	0.06	14.16	0.39	2.66	4.80	11.42	0.22	0.89	0.06	1.82	0.13
286	27.34	0.05	13.77	0.39	2.75	4.83	11.64	0.22	0.83	0.06	1.70	0.12
287	27.37	0.03	13.37	0.40	2.84	4.85	11.87	0.23	0.77	0.06	1.59	0.11
288	27.38	0.01	12.97	0.40	2.93	4.87	12.10	0.23	0.71	0.06	1.48	0.11
289	27.39	0.01	12.58	0.39	3.03	4.88	12.34	0.24	0.67	0.04	1.38	0.10
290	27.38	0.01	12.18	0.40	3.12	4.89	12.59	0.25	0.62	0.05	1.30	0.08
291	27.35	0.03	11.78	0.40	3.21	4.90	12.84	0.25	0.58	0.04	1.22	0.08
292	27.31	0.04	11.38	0.40	3.31	4.90	13.09	0.25	0.55	0.03	1.15	0.07
293	27.26	0.05	10.98	0.40	3.40	4.90	13.34	0.25	0.52	0.03	1.09	0.06
294	27.20	0.06	10.58	0.40	3.50	4.89	13.60	0.26	0.49	0.03	1.03	0.06
295	27.12	0.08	10.19	0.39	3.59	4.87	13.87	0.27	0.47	0.02	0.98	0.05
296	27.03	0.09	9.80	0.39	3.69	4.85	14.13	0.26	0.46	0.01	0.94	0.04
297	26.92	0.11	9.41	0.39	3.78	4.83	14.40	0.27	0.44	0.02	0.91	0.03
298	26.80	0.12	9.02	0.39	3.87	4.80	14.68	0.28	0.44	0.00	0.89	0.02
299	26.67	0.13	8.64	0.38	3.96	4.76	14.95	0.27	0.43	0.01	0.88	0.01
300	26.53	0.14	8.26	0.38	4.06	4.73	15.23	0.28	0.44	0.01	0.88	0.00

TABLE.	V.								VI.		VII.	
Arg.	1								2		3	
	$P_{s.1}$	Diff.	$P_{c.1}$	Diff.	$P_{s.2}$	$P_{c.2}$	δv_1	Diff.	δv_2	Diff.	δv_3	Diff.
	″	″	″	″	″	″	″	″	″	″	″	″
300	26.53		8.26		4.06	4.73	15.23		0.44		0.88	
301	26.37	0.16	7.89	0.37	4.14	4.68	15.51	0.28	0.44	0.00	0.88	0.00
302	26.20	0.17	7.52	0.37	4.23	4.64	15.80	0.29	0.45	0.01	0.89	0.01
303	26.02	0.18	7.16	0.36	4.31	4.59	16.08	0.28	0.47	0.02	0.91	0.02
304	25.82	0.20	6.80	0.36	4.40	4.43	16.37	0.29	0.49	0.02	0.94	0.03
305	25.62	0.20	6.45	0.35	4.47	4.47	16.65	0.28	0.52	0.03	0.98	0.04
306	25.40	0.22	6.10	0.35	4.55	4.41	16.95	0.30	0.55	0.03	1.03	0.05
307	25.17	0.23	5.76	0.34	4.62	4.34	17.24	0.29	0.58	0.03	1.09	0.06
308	24.92	0.25	5.43	0.33	4.69	4.27	17.53	0.29	0.62	0.04	1.15	0.06
309	24.67	0.25	5.11	0.32	4.76	4.20	17.82	0.29	0.66	0.04	1.22	0.07
310	24.41	0.26	4.80	0.31	4.83	4.12	18.12	0.30	0.71	0.05	1.30	0.08
311	24.14	0.27	4.49	0.31	4.89	4.04	18.41	0.29	0.76	0.05	1.38	0.08
312	23.85	0.29	4.19	0.30	4.94	3.96	18.71	0.30	0.82	0.06	1.48	0.10
313	23.56	0.29	3.90	0.29	5.00	3.87	19.00	0.29	0.88	0.06	1.59	0.11
314	23.26	0.30	3.62	0.28	5.05	3.78	19.29	0.29	0.95	0.07	1.70	0.11
315	22.94	0.32	3.35	0.27	5.09	3.69	19.58	0.29	1.02	0.07	1.82	0.12
316	22.62	0.32	3.08	0.27	5.13	3.59	19.87	0.29	1.09	0.07	1.95	0.13
317	22.29	0.33	2.83	0.25	5.17	3.50	20.16	0.29	1.17	0.08	2.09	0.14
318	21.95	0.34	2.59	0.24	5.20	3.40	20.45	0.29	1.25	0.08	2.24	0.15
319	21.61	0.34	2.36	0.23	5.23	3.30	20.73	0.28	1.34	0.09	2.39	0.15
320	21.25	0.36	2.14	0.22	5.25	3.20	21.02	0.29	1.43	0.09	2.55	0.16
321	20.89	0.36	1.93	0.21	5.27	3.10	21.29	0.27	1.53	0.10	2.72	0.17
322	20.53	0.36	1.73	0.20	5.28	2.99	21.57	0.28	1.63	0.10	2.90	0.18
323	20.15	0.38	1.54	0.19	5.29	2.89	21.84	0.27	1.73	0.10	3.09	0.19
324	19.78	0.37	1.36	0.18	5.30	2.78	22.12	0.28	1.84	0.11	3.28	0.19
325	19.39	0.39	1.20	0.16	5.29	2.68	22.38	0.26	1.96	0.12	3.48	0.20
326	19.00	0.39	1.04	0.16	5.29	2.57	22.65	0.27	2.07	0.11	3.70	0.22
327	18.61	0.39	0.90	0.14	5.28	2.46	22.91	0.26	2.19	0.12	3.92	0.22
328	18.22	0.39	0.77	0.13	5.26	2.36	23.16	0.25	2.32	0.13	4.14	0.22
329	17.82	0.40	0.65	0.12	5.24	2.25	23.41	0.25	2.45	0.13	4.37	0.23
330	17.41	0.41	0.54	0.11	5.22	2.15	23.66	0.25	2.58	0.13	4.61	0.24
331	17.01	0.40	0.45	0.09	5.19	2.05	23.90	0.24	2.72	0.14	4.85	0.24
332	16.60	0.41	0.36	0.09	5.15	1.95	24.13	0.23	2.86	0.14	5.11	0.26
333	16.19	0.41	0.29	0.07	5.12	1.85	24.36	0.23	3.01	0.15	5.37	0.26
334	15.78	0.41	0.24	0.05	5.07	1.75	24.58	0.22	3.16	0.15	5.64	0.27
335	15.37	0.41	0.19	0.05	5.02	1.65	24.80	0.22	3.31	0.15	5.92	0.28
336	14.95	0.42	0.16	0.03	4.97	1.56	25.00	0.20	3.47	0.16	6.21	0.29
337	14.54	0.41	0.13	0.03	4.92	1.47	25.21	0.21	3.63	0.16	6.50	0.29
338	14.13	0.41	0.12	0.01	4.85	1.38	25.40	0.19	3.79	0.16	6.80	0.30
339	13.72	0.41	0.12	0.00	4.79	1.29	25.59	0.19	3.96	0.17	7.11	0.31
340	13.31	0.41	0.13	0.01	4.72	1.21	25.76	0.17	4.13	0.17	7.41	0.30
341	12.90	0.41	0.16	0.03	4.65	1.13	25.93	0.17	4.30	0.17	7.73	0.32
342	12.49	0.41	0.19	0.03	4.57	1.05	26.09	0.16	4.48	0.18	8.06	0.33
343	12.09	0.40	0.24	0.05	4.49	0.98	26.24	0.15	4.66	0.18	8.39	0.33
344	11.69	0.40	0.30	0.06	4.41	0.91	26.39	0.15	4.85	0.19	8.72	0.33
345	11.29	0.40	0.37	0.07	4.32	0.85	26.52	0.13	5.04	0.19	9.06	0.34
346	10.89	0.40	0.46	0.09	4.24	0.79	26.65	0.13	5.23	0.19	9.41	0.35
347	10.50	0.39	0.55	0.09	4.15	0.73	26.76	0.11	5.42	0.19	9.77	0.36
348	10.12	0.38	0.65	0.10	4.05	0.68	26.86	0.10	5.62	0.20	10.13	0.36
349	9.73	0.39	0.77	0.12	3.96	0.63	26.95	0.09	5.83	0.21	10.50	0.37
350	9.35	0.38	0.89	0.12	3.86	0.59	27.03	0.08	6.03	0.20	10.88	0.38

Table.	V.								VI.		VII.	
Arg.	1								2		3	
	$P_{s.1}$	Diff.	$P_{c.1}$	Diff.	$P_{s.2}$	$P_{c.2}$	δv_1	Diff.	δv_2	Diff.	δv_3	Diff.
	″	″	″	″	″	″	″	″	″	″	″	″
350	9.35	0.37	0.89	0.13	3.86	0.59	27.03	0.06	6.03	0.21	10.88	0.38
351	8.98	0.36	1.02	0.15	3.77	0.55	27.09	0.06	6.24	0.21	11.26	0.40
352	8.62	0.36	1.17	0.15	3.66	0.52	27.15	0.05	6.45	0.21	11.66	0.39
353	8.26	0.36	1.32	0.16	3.56	0.49	27.20	0.03	6.66	0.22	12.05	0.40
354	7.90	0.34	1.48	0.18	3.46	0.47	27.23	0.03	6.88	0.22	12.45	0.40
355	7.56	0.34	1.66	0.17	3.36	0.45	27.26	0.01	7.10	0.22	12.85	0.41
356	7.22	0.33	1.83	0.19	3.26	0.43	27.27	0.00	7.32	0.23	13.26	0.42
357	6.89	0.33	2.02	0.20	3.15	0.42	27.27	0.02	7.55	0.23	13.68	0.42
358	6.56	0.31	2.22	0.20	3.05	0.42	27.25	0.03	7.78	0.23	14.10	0.42
359	6.25	0.31	2.42	0.21	2.95	0.42	27.22	0.04	8.01	0.23	14.52	0.43
360	5.94	0.30	2.63	0.22	2.85	0.42	27.18	0.06	8.24	0.24	14.95	0.44
361	5.64	0.29	2.85	0.22	2.75	0.43	27.12	0.07	8.48	0.24	15.39	0.45
362	5.35	0.29	3.07	0.23	2.64	0.44	27.05	0.08	8.72	0.24	15.84	0.44
363	5.06	0.27	3.30	0.24	2.54	0.46	26.97	0.11	8.96	0.24	16.28	0.45
364	4.79	0.26	3.54	0.24	2.45	0.48	26.86	0.11	9.20	0.24	16.73	0.45
365	4.53	0.26	3.78	0.25	2.35	0.50	26.75	0.13	9.44	0.25	17.18	0.46
366	4.27	0.24	4.03	0.25	2.26	0.53	26.62	0.15	9.69	0.25	17.64	0.47
367	4.03	0.24	4.28	0.25	2.16	0.57	26.47	0.16	9.94	0.25	18.11	0.47
368	3.79	0.23	4.53	0.26	2.07	0.60	26.31	0.18	10.19	0.26	18.58	0.47
369	3.56	0.21	4.79	0.26	1.98	0.65	26.13	0.19	10.45	0.25	19.05	0.47
370	3.35	0.21	5.05	0.26	1.89	0.69	25.94	0.20	10.70	0.26	19.52	0.48
371	3.14	0.20	5.31	0.27	1.81	0.74	25.74	0.23	10.96	0.26	20.00	0.48
372	2.94	0.19	5.58	0.27	1.72	0.79	25.51	0.24	11.22	0.26	20.48	0.49
373	2.75	0.17	5.85	0.27	1.65	0.84	25.27	0.25	11.48	0.27	20.97	0.49
374	2.58	0.17	6.12	0.27	1.57	0.90	25.02	0.27	11.75	0.26	21.46	0.49
375	2.41	0.17	6.39	0.27	1.50	0.96	24.75	0.29	12.01	0.27	21.95	0.49
376	2.24	0.15	6.66	0.28	1.42	1.02	24.46	0.30	12.28	0.27	22.44	0.50
377	2.09	0.14	6.94	0.28	1.36	1.08	24.16	0.32	12.55	0.27	22.94	0.50
378	1.95	0.14	7.22	0.27	1.29	1.15	23.84	0.33	12.82	0.27	23.44	0.51
379	1.81	0.13	7.49	0.28	1.23	1.21	23.51	0.35	13.09	0.27	23.95	0.51
380	1.68	0.12	7.77	0.27	1.17	1.28	23.16	0.36	13.36	0.27	24.46	0.51
381	1.56	0.11	8.04	0.28	1.11	1.35	22.80	0.38	13.63	0.28	24.97	0.51
382	1.45	0.11	8.32	0.28	1.06	1.42	22.42	0.39	13.91	0.28	25.48	0.51
383	1.34	0.10	8.60	0.28	1.01	1.49	22.03	0.41	14.19	0.27	25.99	0.52
384	1.24	0.09	8.88	0.27	0.96	1.57	21.62	0.41	14.46	0.28	26.51	0.52
385	1.15	0.09	9.15	0.28	0.92	1.64	21.21	0.44	14.74	0.28	27.03	0.53
386	1.06	0.08	9.43	0.27	0.87	1.72	20.77	0.44	15.02	0.28	27.56	0.52
387	0.98	0.07	9.70	0.28	0.83	1.79	20.33	0.45	15.30	0.28	28.08	0.53
388	0.91	0.07	9.98	0.27	0.79	1.87	19.88	0.46	15.58	0.28	28.61	0.52
389	0.84	0.06	10.25	0.27	0.76	1.95	19.42	0.48	15.86	0.29	29.13	0.53
390	0.78	0.06	10.52	0.27	0.72	2.03	18.94	0.48	16.15	0.28	29.66	0.53
391	0.72	0.05	10.79	0.27	0.70	2.10	18.46	0.49	16.43	0.28	30.19	0.53
392	0.67	0.05	11.06	0.28	0.67	2.18	17.97	0.50	16.71	0.29	30.72	0.53
393	0.62	0.05	11.34	0.26	0.64	2.26	17.47	0.50	17.00	0.28	31.25	0.54
394	0.57	0.04	11.60	0.28	0.62	2.35	16.97	0.52	17.28	0.29	31.79	0.53
395	0.53	0.03	11.88	0.26	0.60	2.43	16.45	0.51	17.57	0.29	32.32	0.54
396	0.50	0.04	12.14	0.28	0.59	2.51	15.94	0.52	17.86	0.28	32.86	0.53
397	0.46	0.03	12.42	0.26	0.57	2.59	15.42	0.52	18.14	0.29	33.39	0.54
398	0.43	0.02	12.68	0.27	0.56	2.67	14.90	0.53	18.43	0.28	33.93	0.53
399	0.41	0.03	12.95	0.27	0.55	2.75	14.37	0.52	18.71	0.29	34.46	0.54
400	0.38		13.22		0.54	2.83	13.85		19.00		35.00	

TABLE.	VIII.	IX.	X.	XI.	XII.	XIII.	TABLE.	VIII.	IX.	X.	XI.	XII.	XIII.
Arg.	4	5	6	7	8	9	Arg.	4	5	6	7	8	9
	δv_4	δv_5	δv_6	δv_7	δv_8	δv_9		δv_4	δv_5	δv_6	δv_7	δv_8	δv_9
	"	"	"	"	"	"		"	"	"	"	"	"
0	0.08	0.15	0.94	0.94	0.30	0.80	200	1.12	0.05	0.06	1.26	0.10	0.20
10	0.08	0.14	0.96	1.06	0.28	0.84	210	1.12	0.06	0.04	1.14	0.12	0.16
20	0.10	0.13	0.97	1.19	0.26	0.88	220	1.10	0.07	0.03	1.01	0.14	0.12
30	0.13	0.12	0.96	1.31	0.24	0.91	230	1.07	0.08	0.04	0.89	0.16	0.09
40	0.18	0.10	0.95	1.43	0.22	0.93	240	1.02	0.10	0.05	0.77	0.18	0.07
50	0.23	0.09	0.93	1.54	0.20	0.94	250	0.97	0.11	0.07	0.66	0.20	0.06
60	0.29	0.08	0.89	1.64	0.18	0.94	260	0.91	0.12	0.11	0.56	0.22	0.06
70	0.36	0.07	0.85	1.72	0.15	0.93	270	0.84	0.13	0.15	0.48	0.25	0.07
80	0.44	0.06	0.79	1.79	0.13	0.90	280	0.76	0.14	0.21	0.41	0.27	0.10
90	0.52	0.05	0.73	1.85	0.12	0.87	290	0.68	0.15	0.27	0.35	0.28	0.13
100	0.60	0.04	0.67	1.88	0.10	0.83	300	0.60	0.16	0.33	0.32	0.30	0.17
110	0.68	0.04	0.60	1.90	0.09	0.78	310	0.52	0.16	0.40	0.30	0.31	0.22
120	0.76	0.03	0.52	1.90	0.08	0.72	320	0.44	0.17	0.48	0.30	0.32	0.28
130	0.84	0.03	0.45	1.87	0.07	0.66	330	0.36	0.17	0.55	0.33	0.33	0.34
140	0.91	0.03	0.38	1.83	0.06	0.59	340	0.29	0.17	0.62	0.37	0.34	0.41
150	0.97	0.03	0.31	1.77	0.06	0.52	350	0.23	0.17	0.69	0.43	0.34	0.48
160	1.02	0.03	0.25	1.69	0.06	0.45	360	0.18	0.17	0.75	0.51	0.34	0.55
170	1.07	0.03	0.19	1.60	0.07	0.38	370	0.13	0.17	0.81	0.60	0.33	0.62
180	1.10	0.04	0.14	1.50	0.07	0.32	380	0.10	0.16	0.86	0.70	0.33	0.68
190	1.12	0.05	0.09	1.40	0.09	0.26	390	0.08	0.15	0.91	0.80	0.31	0.74
200	1.12	0.05	0.06	1.26	0.10	0.20	400	0.08	0.15	0.94	0.94	0.30	0.80

TABLE XIV.

If the date is earlier than 1779, Jan. 4, or later than 1943, Oct. 15, the values of $P_{s.1}$ and $P_{c.1}$ must be corrected as follows, the argument being the year:

Year.	$\Delta P_{s.1}$	$\Delta P_{c.1}$	Year.	$\Delta P_{s.1}$	$\Delta P_{c.1}$	Year.	$\Delta P_{s.1}$	$\Delta P_{c.1}$
							"	"
1614.2	− 56.83	− 31.88	1700.0	− 65.57	− 24.94	1943.8	+ 72.87	+ 16.62
1620.0	− 57.44	− 31.46	1710.0	− 66.53	− 24.02	1950.0	+ 73.39	+ 15.88
1630.0	− 58.49	− 30.73	1720.0	− 67.50	− 23.04	1960.0	+ 74.21	+ 14.68
1640.0	− 59.52	− 29.98	1730.0	− 68.46	− 22.04	1970.0	+ 75.02	+ 13.44
1650.0	− 60.56	− 29.18	1740.0	− 69.40	− 21.00	1980.0	+ 75.81	+ 12.18
1660.0	− 61.58	− 28.36	1750.0	− 70.32	− 19.92	1990.0	+ 76.58	+ 10.88
1670.0	− 62.60	− 27.54	1760.0	− 71.22	− 18.82	2000.0	+ 77.32	+ 9.52
1680.0	− 63.62	− 26.70	1770.0	− 72.10	− 17.68			
1690.0	− 64.60	− 25.84	1779.0	− 72.87	− 16.62			

Between 1779 and 1943, P_s and P_c require no correction. For dates earlier than 1614 or later than 2000, the corrections must be computed from the formulæ.

TABLE XV.

Equation of the Centre.

l	Equation.	Diff.	l	Equation.	Diff.	l	Equation.	Diff.
°	° ′ ″	″	°	° ′ ″	″	°	° ′ ″	″
180	1 38 54.42		225	0 57 42.12		270	0 17 6.17	
181	1 38 10.17	44.25	226	0 56 41.74	60.38	271	0 16 24.17	42.00
182	1 37 25.21	44.96	227	0 55 41.40	60.34	272	0 15 42.92	41.25
183	1 36 39.56	45.65	228	0 54 41.12	60.28	273	0 15 2.45	40.47
184	1 35 53.23	46.33	229	0 53 40.90	60.22	274	0 14 22.76	39 69
185	1 35 6.24	46.99	230	0 52 40.78	60.12	275	0 13 43.86	38.90
186	1 34 18.60	47.64	231	0 51 40.76	60.02	276	0 13 5.77	38.09
187	1 33 30.33	48.27	232	0 50 40.87	59.89	277	0 12 28.50	37.27
188	1 32 41.43	48.90	233	0 49 41.12	59.75	278	0 11 52.06	36.44
189	1 31 51.93	49.50	234	0 48 41.53	59.59	279	0 11 16.46	35.60
190	1 31 1.84	50.09	235	0 47 42.12	59.41	280	0 10 41.71	34.75
191	1 30 11.17	50.67	236	0 46 42.90	59.22	281	0 10 7.82	33.89
192	1 29 19.93	51.24	237	0 45 43.90	59.00	282	0 9 34.81	33.01
193	1 28 28.15	51.78	238	0 44 45.13	58.77	283	0 9 2.69	32.12
194	1 27 35.84	52.31	239	0 43 46.61	58.52	284	0 8 31.46	31.23
195	1 26 43.02	52.82	240	0 42 48.36	58.25	285	0 8 1.13	30.33
196	1 25 49.70	53.32	241	0 41 50.39	57.97	286	0 7 31.72	29.41
197	1 24 55.90	53.80	242	0 40 52.72	57.67	287	0 7 3.23	28.49
198	1 24 1.64	54.26	243	0 39 55.36	57.36	288	0 6 35.67	27.56
199	1 23 6.93	54.71	244	0 38 58.34	57.02	289	0 6 9.06	26.61
200	1 22 11.78	55.15	245	0 38 1.67	56.67	290	0 5 43.39	25.67
201	1 21 16.21	55.57	246	0 37 5.37	56.30	291	0 5 18.68	24.71
202	1 20 20.25	55.96	247	0 36 9.45	55.92	292	0 4 54.94	23.74
203	1 19 23.90	56.35	248	0 35 13.94	55.51	293	0 4 32.18	22.76
204	1 18 27.19	56.71	249	0 34 18.84	55.10	294	0 4 10.40	21.78
205	1 17 30.13	57.06	250	0 33 24.18	54.66	295	0 3 49.60	20.80
206	1 16 32.73	57.40	251	0 32 29.97	54.21	296	0 3 29.80	19.80
207	1 15 35.02	57.71	252	0 31 36.22	53.75	297	0 3 11.00	18.80
208	1 14 37.01	58.01	253	0 30 42.96	53.26	298	0 2 53.21	17.79
209	1 13 38.72	58.29	254	0 29 50.19	52.77	299	0 2 36.44	16.77
210	1 12 40.16	58.56	255	0 28 57.94	52.25	300	0 2 20.68	15.76
211	1 11 41.35	58 81	256	0 28 6.22	51.72	301	0 2 5.95	14.73
212	1 10 42.32	59.03	257	0 27 15.05	51.17	302	0 1 52.26	13.69
213	1 9 43.08	59.24	258	0 26 24.43	50.62	303	0 1 39.60	12.66
214	1 8 43.64	59.44	259	0 25 34.40	50.03	304	0 1 27.97	11.63
215	1 7 44.03	59.61	260	0 24 44.95	49.45	305	0 1 17.39	10.58
216	1 6 44.26	59.77	261	0 23 56.11	48.84	306	0 1 7.85	9.54
217	1 5 44.35	59.91	262	0 23 7.89	48.22	307	0 0 59.36	8.49
218	1 4 44.32	60.03	263	0 22 20.31	47.58	308	0 0 51.93	7.43
219	1 3 44.18	60.14	264	0 21 33.37	46.94	309	0 0 45.55	6.38
220	1 2 43.95	60.23	265	0 20 47.10	46.27	310	0 0 40.24	5.31
221	1 1 43.65	60.30	266	0 20 1.50	45.60	311	0 0 36.00	4.24
222	1 0 43.30	60.35	267	0 19 16.60	44.90	312	0 0 32.82	3.18
223	0 59 42.92	60.38	268	0 18 32.40	44.20	313	0 0 30.71	2.11
224	0 58 42.52	60.40	269	0 17 48.92	43.48	314	0 0 29.67	1.04
225	0 57 42.12	60.40	270	0 17 6.17	42.75	315	0 0 29.70	0.03

TABLE XV.

Equation of the Centre (Continued).

l	Equation.	Diff.	l	Equation.	Diff.	l	Equation.	Diff.
°	° ′ ″	″	°	° ′ ″	″	°	° ′ ″	″
315	0 0 29.70		0	0 18 11.18		45	1 0 24.20	
316	0 0 30.80	1.10	1	0 18 55.91	44.73	46	1 1 26.40	62.20
317	0 0 32.96	2.16	2	0 19 41.40	45.49	47	1 2 28.56	62.16
318	0 0 36.20	3.24	3	0 20 27.63	46.23	48	1 3 30.65	62.09
319	0 0 40.50	4.30	4	0 21 14.59	46.96	49	1 4 32.67	62.02
320	0 0 45.88	5.38	5	0 22 2.26	47.67	50	1 5 34.58	61.91
321	0 0 52.33	6.45	6	0 22 50.63	48.37	51	1 6 36.37	61.79
322	0 0 59.84	7.51	7	0 23 39.68	49.05	52	1 7 38.02	61.65
323	0 1 8.42	8.58	8	0 24 29.40	49.72	53	1 8 39.51	61.49
324	0 1 18.06	9.64	9	0 25 19.78	50.38	54	1 9 40.82	61.31
325	0 1 28.76	10.70	10	0 26 10.79	51.01	55	1 10 41.93	61.11
326	0 1 40.52	11.76	11	0 27 2.43	51.64	56	1 11 42.82	60.89
327	0 1 53.34	12.82	12	0 27 54.67	52.24	57	1 12 43.46	60.64
328	0 2 7.21	13.87	13	0 28 47.50	52.83	58	1 13 43.85	60.39
329	0 2 22.13	14.92	14	0 29 40.91	53.41	59	1 14 43.96	60.11
330	0 2 38.10	15.97	15	0 30 34.87	53.96	60	1 15 43.78	59.82
331	0 2 55.11	17.01	16	0 31 29.38	54.51	61	1 16 43.28	59.50
332	0 3 13.16	18.05	17	0 32 24.41	55.03	62	1 17 42.45	59.17
333	0 3 32.24	19.08	18	0 33 19.95	55.54	63	1 18 41.27	58.82
334	0 3 52.35	20.11	19	0 34 15.97	56.02	64	1 19 39.71	58.44
335	0 4 13.48	21.13	20	0 35 12.47	56.50	65	1 20 37.76	58.05
336	0 4 35.62	22.14	21	0 36 9.42	56.95	66	1 21 35.41	57.65
337	0 4 58.78	23.16	22	0 37 6.81	57.39	67	1 22 32.62	57.21
338	0 5 22.94	24.16	23	0 38 4.61	57.80	68	1 23 29.39	56.77
339	0 5 48.09	25.15	24	0 39 2.81	58.20	69	1 24 25.70	56.31
340	0 6 14.24	26.15	25	0 40 1.40	58.59	70	1 25 21.53	55.83
341	0 6 41.37	27.13	26	0 41 0.35	58.95	71	1 26 16.87	55.34
342	0 7 9.47	28.10	27	0 41 59.64	59.29	72	1 27 11.69	54.82
343	0 7 38.54	29.07	28	0 42 59.26	59.62	73	1 28 5.97	54.28
344	0 8 8.57	30.03	29	0 43 59.19	59.93	74	1 28 59.71	53.74
345	0 8 39.54	30.97	30	0 44 59.41	60.22	75	1 29 52.88	53.17
346	0 9 11.46	31.92	31	0 45 59.90	60.49	76	1 30 45.46	52.58
347	0 9 44.30	32.84	32	0 47 0.63	60.73	77	1 31 37.45	51.99
348	0 10 18.07	33.77	33	0 48 1.60	60.97	78	1 32 28.82	51.37
349	0 10 52.74	34.67	34	0 49 2.78	61.18	79	1 33 19.55	50.73
350	0 11 28.32	35.58	35	0 50 4.16	61.38	80	1 34 9.64	50.09
351	0 12 4.79	36.47	36	0 51 5.71	61.55	81	1 34 59.06	49.42
352	0 12 42.14	37.35	37	0 52 7.41	61.70	82	1 35 47.80	48.74
353	0 13 20.35	38.21	38	0 53 9.25	61.84	83	1 36 35.85	48.05
354	0 13 59.42	39.07	39	0 54 11.20	61.95	84	1 37 23.19	47.34
355	0 14 39.34	39.92	40	0 55 13.25	62.05	85	1 38 9.80	46.61
356	0 15 20.09	40.75	41	0 56 15.37	62.12	86	1 38 55.67	45.87
357	0 16 1.66	41.57	42	0 57 17.54	62.17	87	1 39 40.80	45.13
358	0 16 44.04	42.38	43	0 58 19.75	62.21	88	1 40 25.15	44.35
359	0 17 27.22	43.18	44	0 59 21.98	62.23	89	1 41 8.73	43.58
360	0 18 11.18	43.96	45	1 0 24.20	62.22	90	1 41 51.51	42 78

TABLE XV.

Equation of the Centre (Concluded).

l	Equation.	Diff.	l	Equation.	Diff.	l	Equation.	Diff.
°	° ′ ″	″	°	° ′ ″	″	°	° ′ ″	″
90	1 41 51.51		120	1 56 10.41		150	1 54 54.44	
91	1 42 33.48	41.97	121	1 56 23.47	13.06	151	1 54 35.48	18.96
92	1 43 14.63	41.15	122	1 56 35.47	12.00	152	1 54 15.50	19.98
93	1 43 54.95	40.32	123	1 56 46.39	10.92	153	1 53 54.51	20.99
94	1 44 34.42	39.47	124	1 56 56.24	9.85	154	1 53 32.52	21.99
95	1 45 13.04	38.62	125	1 57 5.02	8.78	155	1 53 9.53	22.99
96	1 45 50.78	37.74	126	1 57 12.72	7.70	156	1 52 45.55	23.98
97	1 46 27.65	36.87	127	1 57 19.34	6.62	157	1 52 20.59	24.96
98	1 47 3.62	35.97	128	1 57 24.87	5.53	158	1 51 54.66	25.93
99	1 47 38.69	35.07	129	1 57 29.33	4.46	159	1 51 27.76	26.90
100	1 48 12.85	34.16	130	1 57 32.70	3.37	160	1 50 59.91	27.85
101	1 48 46.08	33.23	131	1 57 34.99	2.29	161	1 50 31.11	28.80
102	1 49 18.38	32.30	132	1 57 36.20	1.21	162	1 50 1.38	29.73
103	1 49 49.73	31.35	133	1 57 36.32	0.12	163	1 49 30.71	30.67
104	1 50 20.13	30.40	134	1 57 35.36	0.96	164	1 48 59.13	31.58
105	1 50 49.57	29.44	135	1 57 33.31	2.05	165	1 48 26.64	32.49
106	1 51 18.03	28.46	136	1 57 30.19	3.12	166	1 47 53.25	33.39
107	1 51 45.52	27.49	137	1 57 25.98	4.21	167	1 47 18.97	34.28
108	1 52 12.01	26.49	138	1 57 20.70	5.28	168	1 46 43.82	35.15
109	1 52 37.51	25.50	139	1 57 14.34	6.36	169	1 46 7.80	36.02
110	1 53 2.01	24.50	140	1 57 6.91	7.43	170	1 45 30.92	36.88
111	1 53 25.50	23.49	141	1 56 58.41	8.50	171	1 44 53.20	37.72
112	1 53 47.97	22.47	142	1 56 48.84	9.57	172	1 44 14.65	38.55
113	1 54 9.42	21.45	143	1 56 38.21	10.63	173	1 43 35.28	39.37
114	1 54 29.84	20.42	144	1 56 26.52	11.69	174	1 42 55.10	40.18
115	1 54 49.22	19.38	145	1 56 13.78	12.74	175	1 42 14.13	40.97
116	1 55 7.56	18.34	146	1 55 59.99	13.79	176	1 41 32.38	41.75
117	1 55 24.85	17.29	147	1 55 45.16	14.83	177	1 40 49.85	42.53
118	1 55 41.10	16.25	148	1 55 29.28	15.88	178	1 40 6.57	43.28
119	1 55 56.28	15.18	149	1 55 12.38	16.90	179	1 39 22.55	44.02
120	1 56 10.41	14.13	150	1 54 54.44	17.94	180	1 38 37.80	44.75

TABLE XVI.

Reduction to the Ecliptic.

Argument u.				1800	1900	2000	Diff. 100 Y.	Argument u.				1800	1900	2000	Diff. 100 Y.
°	°	°	°	"	"	"	"	°	°	°	°	"	"	"	"
0	90	180	270	60.00	60.00	60.00	0.00	135	315	135	315	110.23	109.72	109.21	0.51
1	89	181	269	58.25	58.26	58.28	0.01	134	316	136	314	110.20	109.70	109.18	0.51
2	88	182	268	56.50	56.53	56.57	0.03	133	317	137	313	110.11	109.61	109.10	0.51
3	87	183	267	54.75	54.80	54.84	0.05	132	318	138	312	109.96	109.45	108.95	0.50
4	86	184	266	53.01	53.07	53.14	0.07	131	319	139	311	109.74	109.24	108.74	0.50
5	85	185	265	51.27	51.36	51.45	0.09	130	320	140	310	109.47	108.97	108.47	0.50
6	84	186	264	49.55	49.66	49.76	0.11	129	321	141	309	109.14	108.64	108.14	0.50
7	83	187	263	47.85	47.97	48.09	0.12	128	322	142	308	108.74	108.25	107.76	0.49
8	82	188	262	46.15	46.29	46.43	0.14	127	323	143	307	108.29	107.80	107.32	0.49
9	81	189	261	44.48	44.63	44.79	0.15	126	324	144	306	107.78	107.30	106.81	0.48
10	80	190	260	42.82	42.99	43.16	0.17	125	325	145	305	107.21	106.73	106.25	0.48
11	79	191	259	41.18	41.37	41.56	0.19	124	326	146	304	106.58	106.11	105.64	0.47
12	78	192	258	39.57	39.78	39.98	0.21	123	327	147	303	105.90	105.44	104.97	0.46
13	77	193	257	37.98	38.20	38.43	0.22	122	328	148	302	105.15	104.70	104.24	0.45
14	76	194	256	36.42	36.66	36.90	0.24	121	329	149	301	104.35	103.91	103.46	0.44
15	75	195	255	34.88	35.14	35.40	0.26	120	330	150	300	103.50	103.06	102.62	0.44
16	74	196	254	33.38	33.65	33.93	0.27	119	331	151	299	102.60	102.17	101.74	0.43
17	73	197	253	31.91	32.20	32.49	0.29	118	332	152	298	101.64	101.22	100.80	0.42
18	72	198	252	30.47	30.78	31.08	0.31	117	333	153	297	100.64	100.23	99.82	0.41
19	71	199	251	29.07	29.39	29.71	0.32	116	334	154	296	99.58	99.18	98.78	0.40
20	70	200	250	27.71	28.03	28.37	0.33	115	335	155	295	98.48	98.09	97.69	0.39
21	69	201	249	26.39	26.73	27.07	0.34	114	336	156	294	97.33	96.95	96.57	0.38
22	68	202	248	25.11	25.46	25.82	0.35	113	337	157	293	96.13	95.77	95.40	0.36
23	67	203	247	23.87	24.23	24.60	0.36	112	338	158	292	94.89	94.54	94.18	0.35
24	66	204	246	22.67	23.05	23.43	0.38	111	339	159	291	93.61	93.27	92.93	0.34
25	65	205	245	21.52	21.91	22.31	0.39	110	340	160	290	92.29	91.96	91.63	0.33
26	64	206	244	20.42	20.82	21.22	0.40	109	341	161	289	90.93	90.61	90.29	0.32
27	63	207	243	19.36	19.77	20.18	0.41	108	342	162	288	89.53	89.22	88.92	0.31
28	62	208	242	18.36	18.78	19.20	0.42	107	343	163	287	88.09	87.80	87.51	0.29
29	61	209	241	17.40	17.83	18.26	0.43	106	344	164	286	86.62	86.35	86.07	0.27
30	60	210	240	16.50	16.94	17.38	0.44	105	345	165	285	85.12	84.86	84.60	0.26
31	59	211	239	15.65	16.09	16.54	0.44	104	346	166	284	83.58	83.34	83.10	0.24
32	58	212	238	14.85	15.30	15.76	0.45	103	347	167	283	82.02	81.80	81.57	0.22
33	57	213	237	14.10	14.56	15.03	0.46	102	348	168	282	80.43	80.22	80.02	0.21
34	56	214	236	13.42	13.89	14.36	0.47	101	349	169	281	78.82	78.63	78.44	0.19
35	55	215	235	12.79	13.27	13.75	0.48	100	350	170	280	77.18	77.01	76.84	0.17
36	54	216	234	12.22	12.70	13.19	0.48	99	351	171	279	75.52	75.37	75.21	0.15
37	53	217	233	11.71	12.20	12.68	0.49	98	352	172	278	73.85	73.71	73.57	0.14
38	52	218	232	11.26	11.75	12.24	0.49	97	353	173	277	72.15	72.03	71.91	0.12
39	51	219	231	10.86	11.36	11.86	0.50	96	354	174	276	70.45	70.34	70.24	0.10
40	50	220	230	10.53	11.03	11.53	0.50	95	355	175	275	68.73	68.64	68.55	0.09
41	49	221	229	10.26	10.76	11.26	0.50	94	356	176	274	66.99	66.93	66.86	0.07
42	48	222	228	10.04	10.55	11.05	0.50	93	357	177	273	65.25	65.20	65.16	0.05
43	47	223	227	9.89	10.39	10.90	0.51	92	358	178	272	63.50	63.47	63.43	0.03
44	46	224	226	9.80	10.30	10.82	0.51	91	359	179	271	61.75	61.74	61.72	0.01
45	45	225	225	9.77	10.28	10.79	0.51	90	0	180	270	60.00	60.00	60.00	0.00

TABLE XVII.

Coefficients for Perturbations of Log. Radius Vector.

Argument 1.

	0		50		100		150		200		250		300		350	
	$R_{s.1}$	$R_{c.1}$	$R_{s.1}$	$R_{c.1}$	$R_{s.1}$	$R_{c.1}$	$R_{s.1}$	$R_{c.1}$	$R_{s.1}$	$R_{c.1}$	$R_{s.1}$	$R_{c.1}$	$R_{s.1}$	$R_{c.1}$	$R_{s.1}$	$R_{c.1}$
0	131	23	40	26	34	170	176	142	131	45	78	142	212	170	214	26
1	130	23	37	28	36	172	178	139	129	45	79	145	214	168	212	24
2	130	23	35	30	39	174	180	136	126	45	81	147	216	166	209	22
3	129	23	32	32	41	176	181	133	124	45	82	150	218	163	207	20
4	129	23	30	35	44	178	183	130	122	46	84	152	220	160	204	18
5	128	23	28	37	46	180	184	127	120	46	86	155	222	158	202	17
6	127	23	26	39	49	181	185	124	118	47	88	157	224	156	199	16
7	127	22	24	42	51	183	186	121	116	47	91	160	226	153	197	15
8	126	21	22	45	54	185	186	119	113	48	93	162	227	151	194	15
9	126	21	20	48	57	185	187	116	111	49	96	165	229	148	191	14
10	125	20	18	51	60	186	187	113	109	50	98	167	230	146	189	13
11	124	19	16	54	63	186	187	110	107	51	100	169	232	143	187	12
12	123	18	14	57	66	187	187	108	104	52	103	171	233	140	184	11
13	123	18	13	60	70	187	187	105	102	53	105	173	235	138	182	10
14	122	17	11	64	73	188	187	102	100	54	108	175	237	135	179	9
15	121	16	10	67	76	188	187	99	97	56	110	177	238	132	177	9
16	120	15	9	70	79	189	187	96	95	57	113	178	239	129	175	9
17	118	15	8	73	82	190	186	93	93	59	116	180	240	126	172	9
18	117	14	8	76	86	191	185	90	92	60	119	181	241	122	170	9
19	115	13	7	79	89	192	184	88	90	61	122	183	241	119	167	9
20	113	13	7	82	92	192	183	85	89	63	125	184	242	116	165	9
21	111	13	6	85	95	192	183	83	87	65	128	185	242	113	163	9
22	110	13	6	88	98	190	182	80	85	67	131	186	243	109	161	10
23	108	12	5	92	102	189	182	78	83	70	134	187	244	105	160	10
24	106	12	5	95	105	189	181	76	81	72	137	187	244	102	158	11
25	104	11	4	98	108	188	180	74	80	74	140	188	244	98	156	11
26	102	11	4	102	111	187	178	72	79	76	143	189	244	95	154	12
27	100	10	4	105	115	187	177	70	78	78	146	190	244	92	152	12
28	98	10	5	109	118	186	175	67	77	80	150	191	244	88	150	12
29	95	9	5	113	121	185	173	65	76	83	153	192	243	85	148	13
30	93	9	6	116	125	184	171	63	75	85	156	192	243	82	147	13
31	91	9	6	119	128	183	170	61	74	88	158	192	243	79	146	14
32	88	9	7	122	131	181	168	60	73	90	161	191	242	76	144	14
33	86	9	7	126	134	180	167	59	72	93	164	190	242	73	143	15
34	83	9	8	129	137	178	166	57	72	96	167	189	241	70	142	15
35	81	9	8	132	140	177	165	56	71	99	170	188	240	67	141	16
36	78	9	9	135	143	175	163	54	70	102	173	188	239	64	140	17
37	76	10	10	138	146	173	160	53	70	105	176	187	238	60	139	18
38	73	11	12	140	149	171	158	51	69	108	180	187	237	57	138	18
39	70	12	13	143	151	169	155	50	69	110	183	186	235	54	138	19
40	67	13	16	146	154	167	153	49	69	113	186	186	234	51	137	20
41	64	14	17	148	156	165	151	48	69	116	189	185	232	48	136	21
42	62	15	19	151	159	162	148	48	70	119	191	184	230	45	136	21
43	59	15	21	153	162	160	146	48	70	121	194	183	228	42	135	22
44	57	16	22	156	164	157	144	47	71	124	197	181	226	39	134	22
45	54	17	24	158	166	155	142	47	72	127	200	180	224	37	134	22
46	51	18	26	160	168	152	140	46	73	130	202	178	222	35	133	23
47	49	20	28	163	170	150	138	45	74	133	205	176	220	32	133	23
48	46	22	30	166	172	147	135	45	75	136	207	174	218	30	132	23
49	43	24	32	168	174	145	133	45	77	139	210	172	216	28	131	23
50	40	26	34	170	176	142	131	45	78	142	212	170	214	26	131	23

Note.—Before 1779 and after 1943, we have

$\triangle R_{s.1} = \quad 10.53 \ \triangle P_{c.1}$ 1614 — 1778 $\delta \log r = -314$.

$\triangle R_{c.1} = -10.53 \ \triangle P_{s.1}$ 1943 — 2108 $\delta \log r = +314$.

Perturbations of Logarithm of Radius Vector.

	TABLE XVIII.				TABLE XIX.				TABLE XX.				
	Argument 1.				Argument 2.				Argument 3.				
Arg.	0	50	100	150	0	50	100	150	0	50	100	150	
0	743	387	58	5	801	681	396	119	1401	1196	700	204	50
1	743	378	54	5	801	676	390	115	1401	1188	689	196	49
2	743	369	51	6	801	671	383	111	1400	1180	678	188	48
3	742	361	48	6	801	666	377	107	1400	1172	667	181	47
4	740	352	44	7	800	662	371	103	1399	1163	656	174	46
5	738	343	41	7	800	657	365	99	1398	1155	645	167	45
6	736	334	38	7	800	652	359	95	1397	1147	634	160	44
7	733	325	35	8	799	647	353	91	1396	1138	623	153	43
8	730	316	33	9	798	642	346	88	1395	1130	613	146	42
9	726	307	30	9	797	637	340	84	1393	1121	602	139	41
10	722	298	28	10	796	632	334	80	1392	1112	591	133	40
11	718	290	26	11	795	627	328	77	1390	1103	580	127	39
12	713	282	24	11	794	621	322	73	1388	1094	570	121	38
13	708	274	23	12	793	616	316	70	1386	1085	559	115	37
14	702	267	21	13	791	610	310	67	1384	1075	548	109	36
15	696	259	19	14	790	605	304	64	1382	1066	537	103	35
16	690	251	17	14	788	600	298	61	1379	1057	526	97	34
17	684	244	16	15	787	594	292	57	1377	1047	515	91	33
18	678	236	14	15	785	589	286	54	1374	1038	504	85	32
19	672	229	13	16	783	583	280	51	1370	1028	493	80	31
20	665	222	12	16	781	578	274	48	1367	1018	483	75	30
21	658	215	10	16	779	573	268	45	1364	1008	473	70	29
22	651	207	9	17	777	567	262	43	1360	998	463	65	28
23	643	200	8	18	775	561	257	40	1356	988	452	60	27
24	635	192	6	19	772	555	251	38	1352	978	442	56	26
25	626	185	5	20	770	549	245	36	1348	968	432	52	25
26	617	179	4	20	767	543	239	34	1344	958	422	48	24
27	608	172	3	20	765	537	234	31	1339	948	412	44	23
28	599	166	3	21	762	532	228	29	1335	937	402	40	22
29	590	160	2	21	759	526	223	27	1330	927	392	36	21
30	580	154	2	21	756	520	218	25	1325	917	382	33	20
31	570	148	2	22	753	513	213	23	1320	907	372	30	19
32	561	143	2	22	750	507	207	22	1315	896	362	26	18
33	551	137	2	23	747	500	202	20	1309	885	353	23	17
34	542	131	3	23	743	494	196	19	1303	874	343	21	16
35	532	125	3	24	740	488	191	18	1297	863	334	18	15
36	522	120	3	24	736	482	186	17	1291	852	325	16	14
37	513	115	3	25	733	476	181	16	1285	841	315	14	13
38	503	110	4	25	729	470	176	14	1279	830	306	12	12
39	494	105	4	26	726	464	171	13	1273	820	297	10	11
40	484	100	4	26	722	458	166	12	1267	809	288	8	10
41	474	95	4	26	718	452	161	11	1261	798	279	7	9
42	464	91	4	27	714	446	156	10	1254	787	270	5	8
43	455	86	4	27	711	439	151	10	1247	777	262	4	7
44	445	81	4	27	707	432	146	9	1240	766	253	3	6
45	435	77	4	28	703	427	141	8	1233	755	245	2	5
46	425	73	4	28	699	421	137	8	1226	744	237	1	4
47	416	69	4	28	694	415	132	8	1219	733	228	0	3
48	406	65	5	29	690	408	128	7	1212	722	220	0	2
49	397	61	5	29	685	402	123	7	1204	711	212	0	1
50	387	58	5	29	681	396	119	7	1196	700	204	0	0
	350	300	250	200	350	300	250	200	350	300	250	200	Arg.

TABLE XXI.

Principal Term of the Logarithm of the Radius Vector.

Argument l.

l	1.4		l	1.4		l	1.4	
°			°			°		
180	806676		240	815373		300	788978	
181	7112	436	241	5192	181	301	8352	626
182	7540	428	242	5001	191	302	7722	630
183	7960	420	243	4799	202	303	7089	633
184	8371	411	244	4587	212	304	6455	634
185	808775	404	245	814364	223	305	785818	637
186	9169	394	246	4130	234	306	5179	639
187	9554	385	247	3885	245	307	4538	641
188	9931	377	248	3631	254	308	3896	642
189	810299	368	249	3366	265	309	3252	644
190	810657	358	250	813092	274	310	782607	645
191	1005	348	251	2807	285	311	1961	646
192	1344	339	252	2513	294	312	1314	647
193	1674	330	253	2208	305	313	0667	647
194	1994	320	254	1894	314	314	0020	647
195	812305	311	255	811570	324	315	779373	647
196	2606	301	256	1237	333	316	8726	647
197	2897	291	257	0895	342	317	8079	647
198	3178	281	258	0543	352	318	7432	647
199	3449	271	259	0182	361	319	6786	646
200	813710	261	260	809812	370	320	776140	646
201	3961	251	261	9433	379	321	5495	645
202	4202	241	262	9045	388	322	4851	644
203	4432	230	263	8648	397	323	4208	643
204	4653	221	264	8242	406	324	3567	641
205	814864	210	265	807827	415	325	772927	640
206	5064	200	266	7404	423	326	2289	638
207	5252	188	267	6972	432	327	1654	635
208	5430	178	268	6532	440	328	1022	632
209	5597	167	269	6084	448	329	0393	629
210	815753	156	270	805629	455	330	769767	626
211	5899	146	271	5166	463	331	9143	624
212	6034	135	272	4696	470	332	8522	621
213	6159	125	273	4217	479	333	7904	618
214	6273	114	274	3731	486	334	7290	614
215	816376	103	275	803236	495	335	766679	611
216	6468	92	276	2735	501	336	6072	607
217	6549	81	277	2227	508	337	5470	602
218	6619	70	278	1712	515	338	4872	598
219	6678	59	279	1191	521	339	4279	593
220	816727	49	280	800663	528	340	763691	588
221	6763	36	281	0128	535	341	3108	583
222	6789	26	282	799588	540	342	2530	578
223	6804	15	283	9041	547	343	1957	573
224	6807	3	284	8488	553	344	1389	568
225	816800	7	285	797930	558	345	760826	563
226	6782	18	286	7366	564	346	0270	556
227	6752	30	287	6796	570	347	759719	551
228	6711	41	288	6221	575	348	9174	545
229	6659	52	289	5641	580	349	8636	538
230	816596	63	290	795056	585	350	758104	532
231	6523	73	291	4467	589	351	7579	525
232	6439	84	292	3873	594	352	7061	518
233	6344	95	293	3274	599	353	6549	512
234	6238	106	294	2671	603	354	6045	504
235	816121	117	295	792063	608	355	755548	497
236	5993	128	296	1452	611	356	5059	489
237	5854	139	297	0838	614	357	4578	481
238	5704	150	298	0221	617	358	4104	474
239	5544	160	299	789601	620	359	3638	466
210	815373	171	300	788978	623	360	753181	457

TABLE XXI.

Principal Term of the Logarithm of the Radius Vector (Continued).

Argument l.

l	1.4		l	1.4		l	1.4	
°			°			°		
0	753181		60	744487		120	772170	
1	2731	450	61	4685	198	121	2811	641
2	2290	441	62	4894	209	122	3454	643
3	1858	432	63	5114	220	123	4098	644
4	1434	424	64	5346	232	124	4744	646
5	751020	415	65	745588	242	125	775392	648
6	0615	405	66	5841	253	126	6041	649
7	0218	397	67	6105	264	127	6691	650
8	749830	388	68	6380	275	128	7343	652
9	9452	378	69	6665	285	129	7996	653
10	749083	369	70	746961	296	130	778650	654
11	8724	359	71	7267	306	131	9303	653
12	8375	349	72	7584	317	132	9956	653
13	8036	339	73	7910	326	133	780609	653
14	7706	330	74	8246	336	134	1262	653
15	747386	320	75	748592	346	135	781915	653
16	7076	310	76	8948	356	136	2567	652
17	6777	299	77	9314	366	137	3219	652
18	6488	289	78	9689	375	138	3869	650
19	6210	278	79	750074	385	139	4518	649
20	745942	268	80	750469	395	140	785166	648
21	5685	257	81	0873	404	141	5812	646
22	5439	246	82	1286	413	142	6456	644
23	5204	235	83	1707	421	143	7098	642
24	4980	224	84	2137	430	144	7738	640
25	744766	214	85	752576	439	145	788376	638
26	4563	203	86	3024	448	146	9011	635
27	4372	191	87	3480	456	147	9642	631
28	4191	181	88	3944	464	148	790271	629
29	4021	170	89	4417	473	149	0897	626
30	743862	159	90	754897	480	150	791519	622
31	3715	147	91	5385	488	151	2138	619
32	3580	135	92	5881	496	152	2753	615
33	3456	124	93	6384	503	153	3364	611
34	3344	112	94	6895	511	154	3971	607
35	743242	102	95	757414	519	155	794575	604
36	3152	90	96	7940	526	156	5174	599
37	3073	79	97	8472	532	157	5768	594
38	3007	66	98	9010	538	158	6357	589
39	2953	54	99	9553	543	159	6941	584
40	742910	43	100	760103	550	160	797519	578
41	2879	31	101	0660	557	161	8093	574
42	2860	19	102	1223	563	162	8661	568
43	2852	8	103	1792	569	163	9223	562
44	2856	4	104	2367	575	164	799779	556
45	742872	16	105	762948	581	165	800330	551
46	2899	27	106	3533	585	166	0875	545
47	2937	38	107	4123	590	167	1413	538
48	2987	50	108	4718	595	168	1944	531
49	3048	61	109	5317	599	169	2468	524
50	743120	72	110	765922	605	170	802985	517
51	3204	84	111	6531	609	171	3496	511
52	3300	96	112	7143	612	172	4000	504
53	3408	108	113	7759	616	173	4497	497
54	3529	121	114	8379	620	174	4986	489
55	743661	132	115	769003	624	175	805468	482
56	3804	143	116	9631	628	176	5942	474
57	3958	154	117	770262	631	177	6408	466
58	4123	165	118	0895	633	178	6866	458
59	4300	177	119	1531	636	179	7317	451
60	744487	187	120	772170	639	180	807759	442

TABLE XXII.

Coefficients for Perturbations of Latitude.

Argument 1.

Arg.	0		100		200		300	
	$B_{s.1}$	$B_{c.1}$	$B_{s.1}$	$B_{c.1}$	$B_{s.1}$	$B_{c.1}$	$B^{c.1}$	$B_{c.1}$
	"	"	"	"	"	"	"	"
0	0.52	0.40	0.41	0.00	0.04	0.18	0.14	0.58
10	0.56	0.35	0.31	0.00	0.04	0.18	0.21	0.65
20	0.61	0.31	0.23	0.03	0.04	0.17	0.30	0.70
30	0.67	0.27	0.15	0.06	0.03	0.18	0.38	0.73
40	0.72	0.23	0.09	0.10	0.02	0.20	0.45	0.73
50	0.73	0.18	0.05	0.13	0.01	0.23	0.50	0.70
60	0.72	0.13	0.03	0.16	0.01	0.28	0.52	0.65
70	0.67	0.08	0.02	0.17	0.02	0.34	0.52	0.59
80	0.59	0.04	0.03	0.18	0.04	0.42	0.51	0.52
90	0.50	0.01	0.04	0.18	0.08	0.50	0.51	0.46
100	0.41	0.00	0.04	0.18	0.14	0.58	0.52	0.40

Perturbations of Latitude.

Arg.	TABLE XXIII. Arg. 5.				TABLE XXIV. Arg. 8.			
	0	100	200	300	0	100	200	300
	"	"	"	"	"	"	"	"
0	−0.30	+0.06	+0.30	−0.06	+0.04	+0.56	−0.04	−0.56
10	−0.29	+0.11	+0.29	−0.11	+0.13	+0.55	−0.13	−0.55
20	−0.27	+0.16	+0.27	−0.16	+0.21	+0.52	−0.21	−0.52
30	−0.24	+0.19	+0.24	−0.19	+0.29	+0.48	−0.29	−0.48
40	−0.21	+0.23	+0.21	−0.23	+0.36	+0.43	−0.36	−0.43
50	−0.17	+0.26	+0.17	−0.26	+0.43	+0.37	−0.43	−0.37
60	−0.12	+0.28	+0.12	−0.28	+0.48	+0.30	−0.48	−0.30
70	−0.08	+0.30	+0.08	−0.30	+0.52	+0.22	−0.52	−0.22
80	−0.03	+0.31	+0.03	−0.31	+0.55	+0.14	−0.55	−0.14
90	+0.02	+0.31	−0.02	−0.31	+0.56	+0.05	−0.56	−0.05
100	+0.06	+0.30	−0.06	−0.30	+0.56	−0.04	−0.56	+0.04

TABLE XXV.

Values of Sin i for every Ten Years.

Year.	1600		1700		1800		1900	
0	8.498705		8.496503		8.494292		8.492066	
10	8485	220	6282	221	4071	221	1842	224
20	8265	220	6061	221	3849	222	1619	223
30	8045	220	5840	221	3627	222	1395	224
40	7825	220	5619	221	3404	223	1171	224
50	8.497605	220	8.495398	221	8.493182	222	8.490947	224
60	7385	220	5177	221	2959	223	0723	224
70	7165	220	4956	221	2736	223	0498	225
80	6944	221	4735	221	2513	223	0274	224
90	6724	220	4513	222	2289	224	8.490049	225
100	8.496503	221	8.494292	221	8.492066	223	8.489824	225

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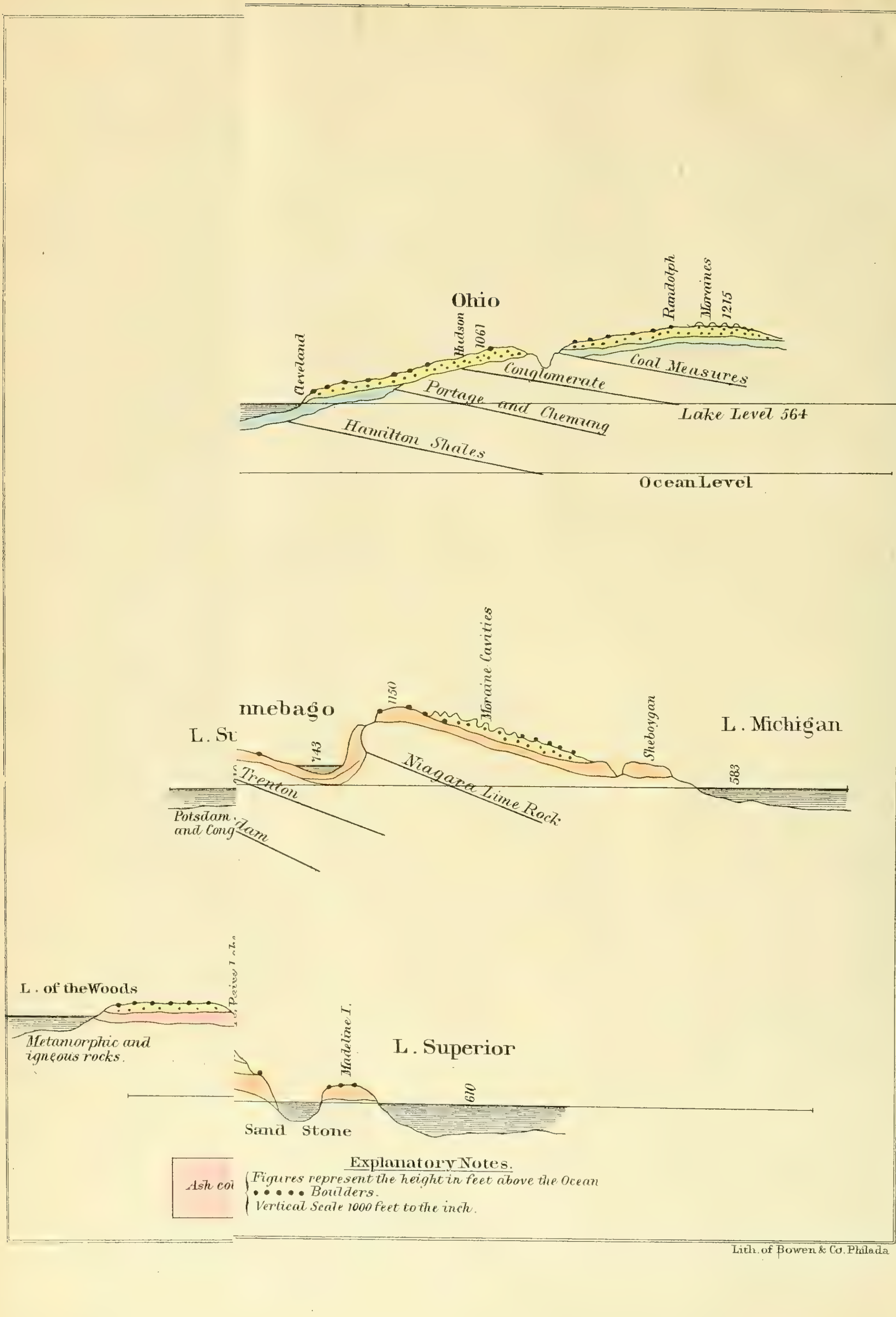
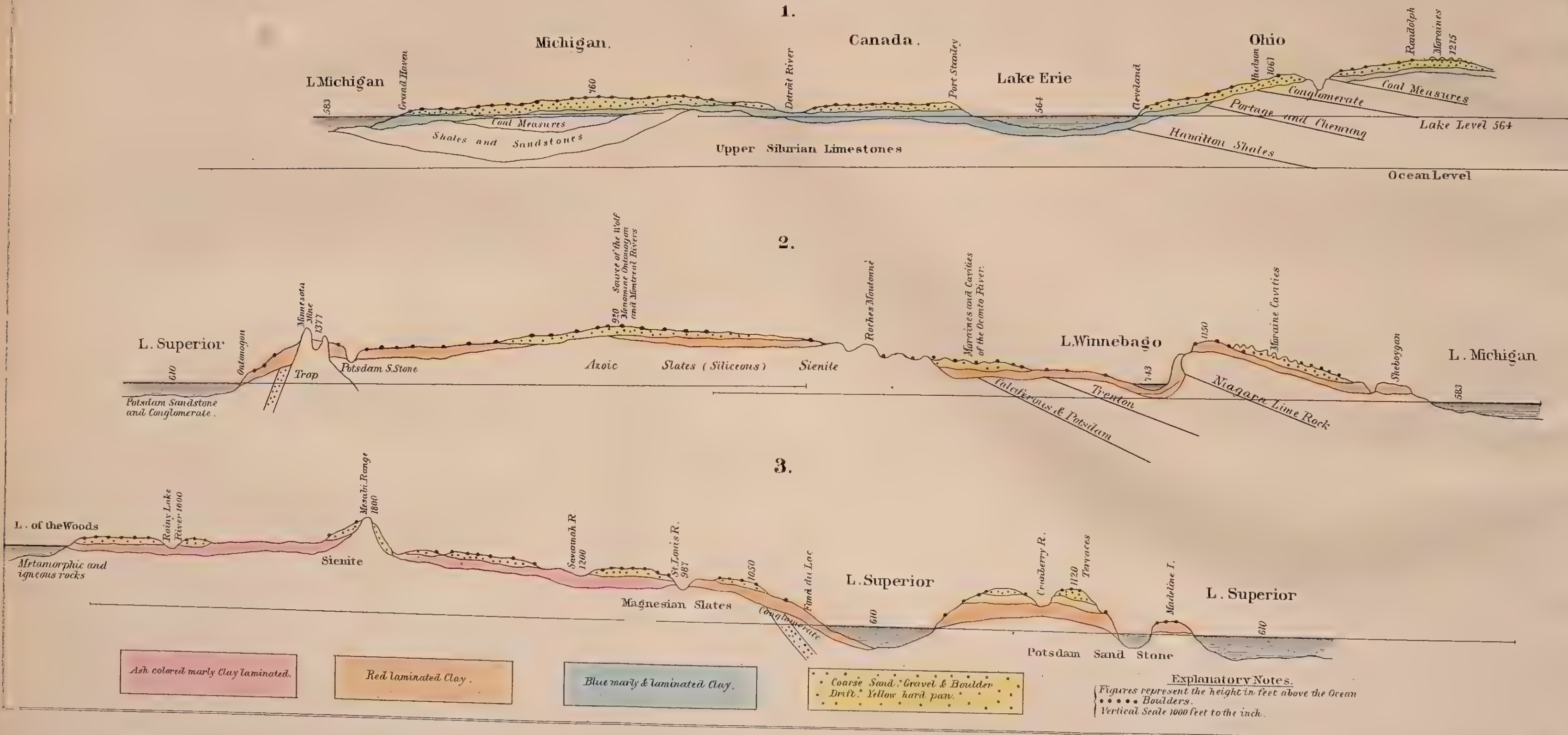
JANUARY, 1866.



Lith. of Bowen & Co. Philada

PROFILE
OF THE
FRESH WATER DRIFT DEPOSITS
FROM
LAKE ERIE TO THE LAKE OF THE WOODS

By
Col! Charles Whittlesey,
CLEVELAND, OHIO.



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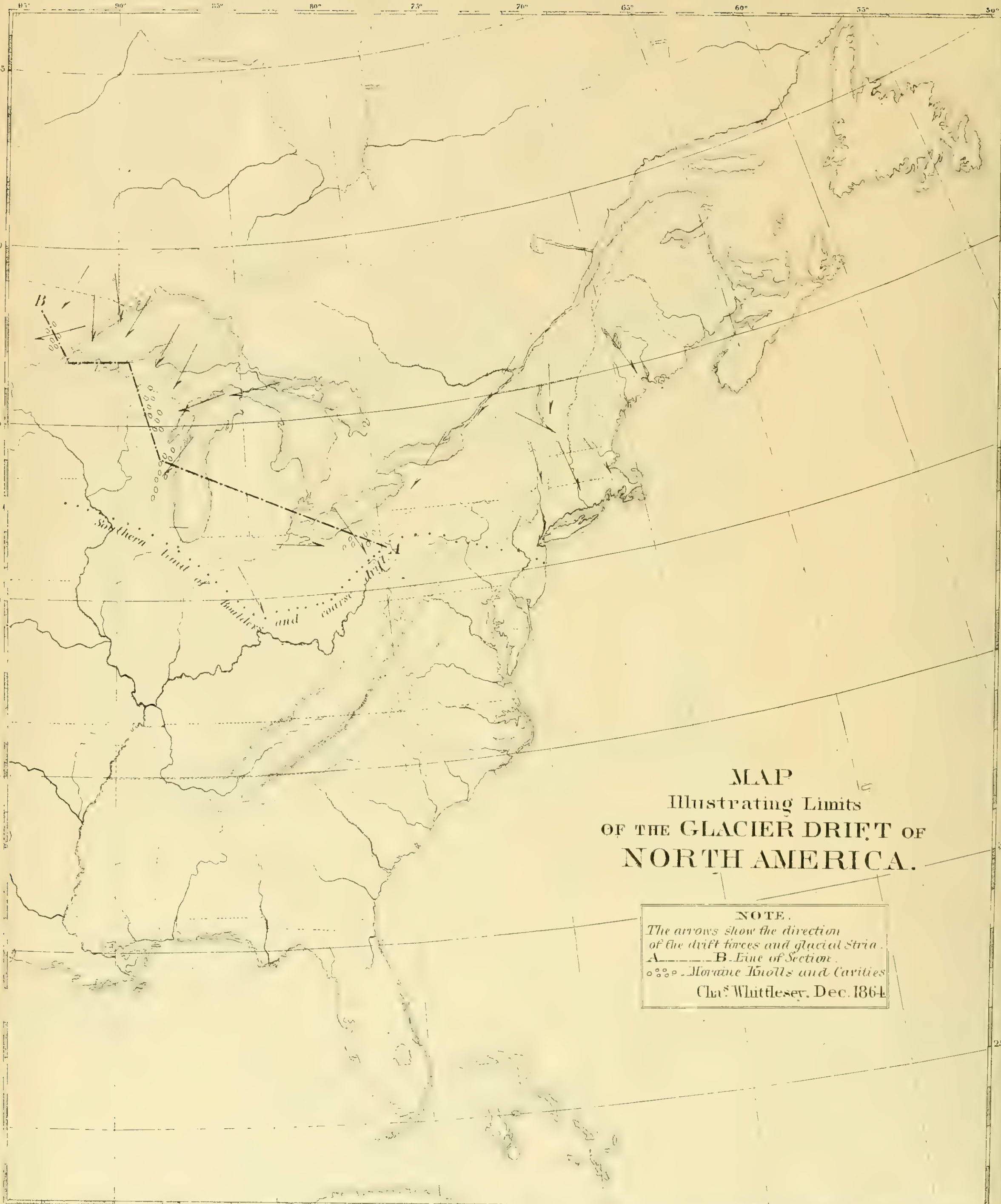

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SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE.
197

ON THE

FRESH-WATER GLACIAL DRIFT

OF THE

NORTHWESTERN STATES.

BY
CHARLES WHITTLESEY.

[ACCEPTED FOR PUBLICATION, JUNE, 1864.]

COMMISSION

TO WHICH THIS PAPER HAS BEEN REFERRED.

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Prof. J. P. Lesley.

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COLLINS, PRINTER,
PHILADELPHIA.

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ON THE

FRESH-WATER GLACIAL DRIFT OF THE NORTHWESTERN STATES.

I HAVE had opportunities during the past twenty-five years, of examining the superficial materials which overlie the indurated rocks, in six of the Northern and Western States, and covering the territory north of the Ohio river and east of the Mississippi, to the national boundary. The length north and south of this area is about eleven degrees of latitude, from the 38th to 49th, its breadth being quite irregular. On the east its boundary is the middle line of the North American lakes from Erie to Superior, and thence northwesterly along Pigeon river and Rainy Lake river to the Lake of the Woods. Over this space I have found what I conceive to be but one formation belonging to the quaternary or post tertiary, having three members. This formation is wholly of fresh water origin, having as yet furnished no specimen of a marine or salt-water character.

To the eastward of Lake Erie, in the valleys of Lakes Ontario and Champlain, and along the St. Lawrence, the shells of the drift are wholly marine. The external characters of the clays in which they are imbedded does not differ materially from those of Lakes Erie, Huron, and Superior, except in color. Farther examination in Northern New York, and on the Canada side of the St. Lawrence, will probably show that the terraces and sand ridges at the west end of Lake Ontario overlap the marine drift towards the east, and are therefore more recent. The ridges and terraces of Lake Ontario extend westerly and connect with those of Lake Erie, which run into those of Lakes St. Clair, Huron, and Michigan, forming one system. They reach up the bays and indentations of the coast of all the lakes, and up the valleys of the rivers.

The ridges are composed of water-washed sand, in which are buried timber, leaves and fragments of trees, of varieties now existing in North America, but principally of a northern growth. Buried timber of the same varieties is common through the entire depth of the superficial materials. Shells are not frequent, but when found are well preserved. The thickness of the drift is very variable, reaching, occasionally, 600 to 1,000 feet; though this is unusual, for it seldom exceeds 200 to 300 feet. This great fresh-water formation, there is reason to believe, extends northerly and westerly on this continent much farther than I have examined it. Various names have been used in describing it, some of which are local, and others intended to represent its age in the "Geological Series." I use the term "glacial drift"

because it expresses what I conceive to be the mode of its origin. Its epoch nearly approaches that of the alluvium. It is so recent that in many cases the buried timber is not decayed or even discolored. As it is due to glacier action from the north, a force which was universal, it must have its counterpart in Northern Europe and Asia.

After these general observations I proceed with the descriptions in detail. The three members are as follows, reckoning in the order of superposition from the surface downwards:—

1st. Coarse sand, gravel, loam, and hard pan, with large boulders of northern rocks, occupying the surface and the heights of land, with little stratification.

2d. Sand and gravel less coarse than No. 1, with irregular bands of clay somewhat laminated, and boulders smaller than in No. 1.

3d. Fine laminated sandy and marly clay of great thickness, of a red, purple, blue, and ash color, with few boulders and little gravel, occupying the valleys of the lakes and rivers.

Wherever there is a great thickness of the superficial materials these divisions can be readily traced, and always in the same order, as shown in the accompanying section. The laminated clays are invariably at the bottom where more than one member exists, and generally rest on the indurated rocks.

Number one occupies the height of land, and frequently lies upon the rock formations without intervention of the other drift beds. It is always coarse and more or less confused. What is known among well-diggers, and canal and railroad contractors, as "hard pan," belongs to this member. The hard pan is the result of a mixture of clay, sand, and gravel, or fragments of rocks, in a confused or imperfectly stratified condition, rendered compact by the nature of the materials and by pressure.

There is a modified form of the drift in and along the edges of the valleys of streams, heretofore known as "valley drift," which, with the resulting terraces, is due to changes and causes, to which reference will be hereafter made. Member number *one* is the seat of the Moraine hillocks and depressions that mark the summits of the country. It is always coarse and imperfectly stratified. The gravel is not derived wholly from distant and northern rocks. The strata, which underlie the drift at different points, are also represented. Where these strata are soft the fragments, torn off by the ice movement, are more easily pulverized, and are, therefore, not transported as far as those of the hard, and especially of the tough igneous rocks.

Sandstone, limestone, and shale from the coal series, and from the Devonian beds, are common. These are in general not as completely rounded, but are more elongated and flatter, with their edges less worn. But representatives from all the rocky strata to the north can be found including the Potsdam sandstone, and other lower Silurian beds; also trap, trachyte, granite, sienite, gneiss, and conglomerate, with the contents of dykes and mineral veins, pieces of iron ore, and boulders of native copper, from Lake Superior.

This upper member of the drift is distinguished by evidences of violence in the action of the glacial forces. It contains the largest and most numerous boulders.

The Moraine hillocks and cavities that are represented on the map near the line of the profile, in Northern Ohio, Wisconsin, and Minnesota, are in this member. It may be considered strange that the coarsest material should occupy the highest drift summits, but such is uniformly the case. These cavities extend below the general surface ten, fifteen, and even one hundred feet, their outline being rudely circular, and their sides as steep as is consistent with stability of the soil.

Fig. 1.

DRIFT CAVITIES, OR "POTASH KETTLES," near Greenbush, Wisconsin. Range of drift hills looking west.
○ ○ ○ Boulders of Northern rocks—base 150 feet above Lake Michigan.

About Lake Winnebago, the pebbles and boulders of the subjacent Niagara limestone constitute a large portion of the mass, with which sand and gravel are intimately mixed. I have traced them one hundred and fifty miles farther in a northerly direction to the Wissakote or Brule river.

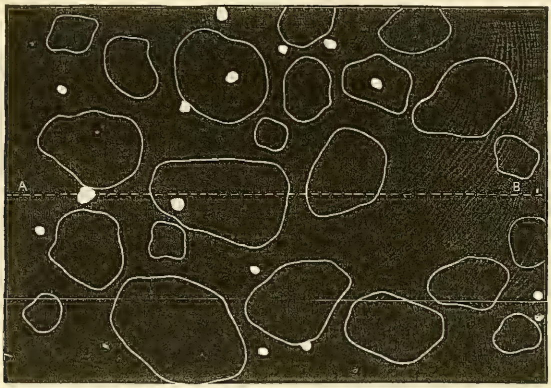
After passing northward beyond the sedimentary rocks above Lake Winnebago, the proportion of sand increases, and also the size and number of the boulders, which are mostly of igneous origin. To form an idea of the appearance of the "potash kettle" country, we may imagine a region of drift moraines inverted, and instead of a surface thickly set with rounded hillocks, suppose it to be occupied by cavities of irregular size and depth. If the grinder of a mastodon were impressed upon a piece of clay the depressions which result would represent the drift cavities as contrasted with drift elevations. In travelling through such a region the explorer frequently finds these hollows so near together that he no sooner rises out of one than he is obliged immediately to descend into another, the diameter of which may not be more than twice or thrice its depth.

There is very seldom any water in the bottom, owing to the loose and porous character of the gravel drift. Boulders are found at the bottom, on the sides, and on the surface around them. Where these cavities are thickly set, as at the source of the Oconto river, and are without hillocks, the rim or edge between them is sometimes so narrow, that large boulders have not base enough to rest upon, and tumble down the sides. (See Fig. 2.)

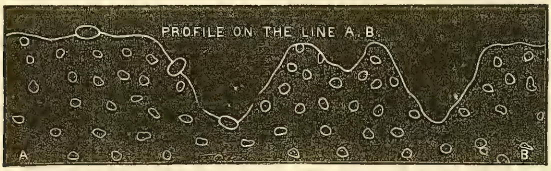
The internal slope is occasionally straight like a funnel, or inverted cone, but oftener cup-shaped or curved in a manner correctly represented by the form of a kettle. In the prairie region of Southern Wisconsin, timber grows within the cavities; as it does on the adjacent lands in clumps, or as separate trees, under the local name of "oak orchards." Farther north, in the thickly timbered country

between the Fox and the Wissakote rivers, the cavities are filled with trees. Near the Wissakote in T. 40 N., R. 18 E. (Wisconsin meridian) at an elevation of 800 feet above Lake Michigan, they are broader and trough like in form; the drift is more sandy, and small lakes, ponds, or marshes, are occasionally seen at the bottom.

Fig. 2.



HORIZONTAL PROJECTION of drift cavities 15 to 60 feet deep, head waters of Oconto river, Wisconsin.
○ ○ ○ Large Boulders of Sienite—350 feet above Lake Michigan.



Of course, the boulders and the gravel are here derived from the azoic and igneous rocks at the north. On the line of the survey for the "Chicago, St. Paul, and Fond du Lac Railroad," in T. 34 N., R. 17 E., on the north of the Peshattego river, at an elevation of 660 feet, the "kettles" are very numerous, and sharply defined. Proceeding southerly, a series of them occur in T. 31 N., R. 17 E., about twenty miles north of the Oconto, the summits of the country being 335 feet above Lake Michigan and 913 feet above the ocean.

Those on the dividing ridge, between the waters of the west branch of the Oconto and the Wolf rivers, in T. 32 N., R. 15 E., have an elevation of 350 to 400 feet, and afford the finest instances of steep and well defined cavities. Terraces and oblong ridges of sand or gravel might be formed by currents and eddies acting upon loose materials. It is not difficult to perceive how mounds, irregular elevations, and undulations, could be thus built up by gradual accretion, above the general surface. But the formation of a system of depressions of an uniform character, over large tracts of country, without natural mounds or ozars, is some-

thing quite different. And yet, this has occurred in the drift, and must therefore be due to a phase of the drift phenomena. The rocks beneath the superficial materials in which these cavities are formed, are everywhere polished and grooved by the drift forces.

At the foot of the Alps, moraines are formed mechanically, by the movements of glaciers, carrying forward earth and stones, which are finally left in rounded heaps on the more level country. Masses of ice become entangled with the loose materials, which in due time melt away and disappear.

I assume it to be a settled point, that the moving force in the drift epoch was glacier ice. Nothing else seems to be adequate to the results we observe. The objections to this view have been removed by the observations of Dr. I. I. Hayes, of the Kane Arctic Expedition, and of Dr. Rink. On the northwest coast of Greenland, which is a vast glacier, the ice is found to be advancing toward the coast over a country comparatively level. It has accomplished a movement not only down inclined surfaces, such as the slopes of mountains and along flat land, but even up acclivities that were opposed to its progress. If the temperature of Greenland or the Arctic Circle were brought down to latitude 40° north, glaciers would exist, in fact, they now occur within 45° of the equator. It is only necessary to suppose the northern hemisphere during the ice period to have been covered with continental ice, to the depth of many hundred feet, as Greenland is now.

This frozen expanse must have been attacked by the heat of the sun most powerfully on the side of the equator. Its southerly limit being at latitude 40°, it would be along this edge that it would be first melted. The conditions of movement in glacier regions would then be supplied, only the field would be a larger one.

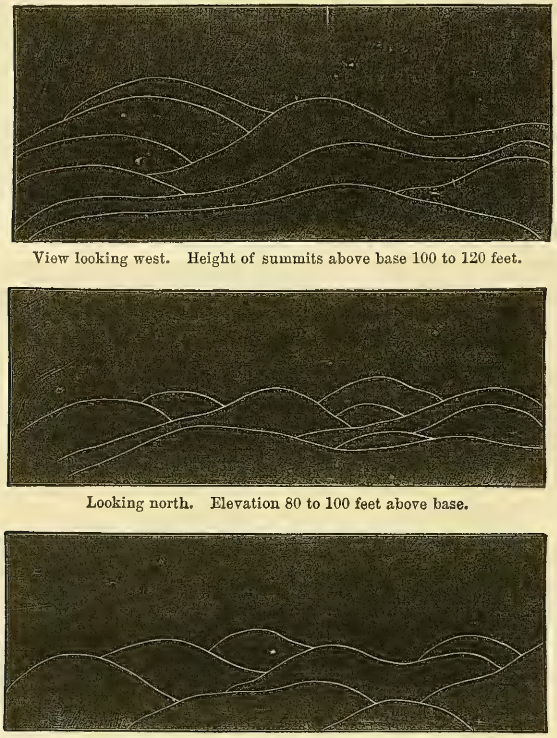
On the north, the extent of the mass would be such, that in that direction, there could be no movement, and the expansion must produce its whole effect in a southerly direction. Thus, so far as resistance in the rear gives rise to motion in front, a fixed mass of ice may be considered equivalent to a central mountain chain. Admitting such a state of things, it follows that along the southern edge of this all-pervading glacier, fragments and masses of ice would be inclosed in, and buried beneath, the drift materials. Sir John Richardson in 1849–'50, while journeying down the Mackenzie river, discovered ice at different depths beneath the surface of the earth, extending to several hundred feet. Although potatoes were raised in the soil at Fort Hope, it did not thaw during the short summer months more than two or three feet in depth. It is reported that in Patagonia, huge piles of stones and ice are seen mingled together for years. The first impression on viewing these depressions of the drift is, that they are due to subsidence.

In the cases just cited, if the mixed mass consisted more of ice than of earth and stones, the surface should be one of pits and depressions. Hillocks or moraines could only occur in such materials where the earthy and imperishable parts are in excess. When the proportions are about equal, there would be both cavities and moraines. In the southerly part of Wisconsin, both forms are observed, but as we proceed northerly the depressions increase in number, and the hillocks or ozars, diminish. As we proceed northerly, there is less of stratification, and a closer approach to the true glacial moraines. The drift cavities in other parts of the

northwest do not differ materially from those of Wisconsin. Those at the head of the Oconto river, and those between Sheboygan and Fond du Lac, are more regular in their outline than they are further north, on the Mesabi Range, in Minnesota. Here on the dividing ridge, between the St. Louis and the Vermilion rivers, the boulders are large, with less gravel and earth filling the interstices. To the westward of the Apostle Islands, in Lake Superior, near Bayfield, Wisconsin, there are huge terraces of boulders, with very little earth, rising from 400 to 600 feet above lake level.

Fig. 3.

Outline views of Moraine Hillocks and Cavities. Randolph, Portage County, Ohio.
Base line about 500 feet above Lake Erie.



View looking west. Height of summits above base 100 to 120 feet.

Looking north. Elevation 80 to 100 feet above base.

Looking southwest. Elevation 70 to 80 feet above base.

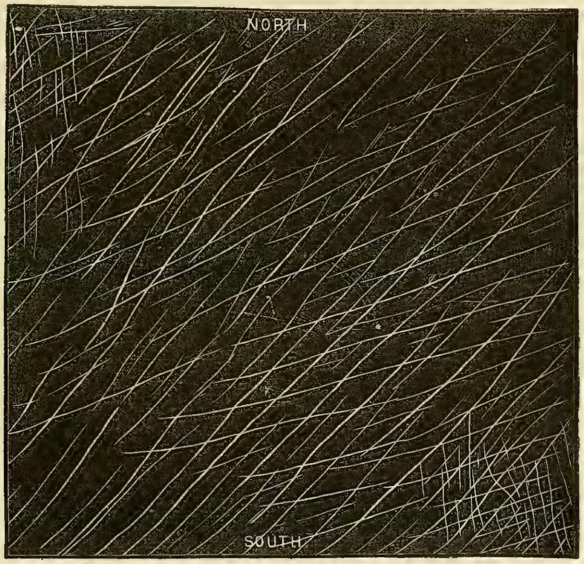
In other places, both north and south of Lake Superior, there are patches of boulders nearly level, from among which the finer materials have been washed away. A few miles to the northeast of the Twin Falls of the Menominee river, in Michigan, there is, on the northern slope of a mountain, a field of boulders, nearly a mile across. Every step in that distance might be taken without touching the soil. The boulders are smoothed and polished by attrition, and are forced

compactly together, like a pavement. On the summit, between the waters of Lake Erie and the Ohio river, in Northeastern Ohio, the elevations and depressions of the upper drift, are less marked but readily distinguishable.

The materials are coarse as compared with the lower members, but less coarse than upon the waters of Lake Superior. There was evidently less intensity in the glacial movement, as we approach its southern limit. Some of the boulders are as large, but their numbers are less. In the township of Green, Summit County, Ohio, there is an erratic block of granite 12 feet long, 10 feet broad, and 7 feet thick.

Along the height of land, there are also patches of boulders of northern and igneous rocks, a few rods across, resembling, on a small scale, those of the Menominee and St. Louis rivers. Although the transporting and sorting action appears to have been more powerful at high levels, the abrading action of the drift forces is as conspicuous in valleys as upon mountains. The limestone strata of Sandusky, Ohio, at the level of Lake Erie, which pass beneath the lake, are as thoroughly worn and striated as the conglomerate, and the coal grits 600 feet above lake level. It is the same at Sheboygan, in Wisconsin, where the Niagara limestone is covered by red clay, which the waves of Lake Michigan wash away from the rocks, leaving exposed large warped surfaces of glacial etchings and polished grooves, perfectly fresh and clean.

Fig. 4.



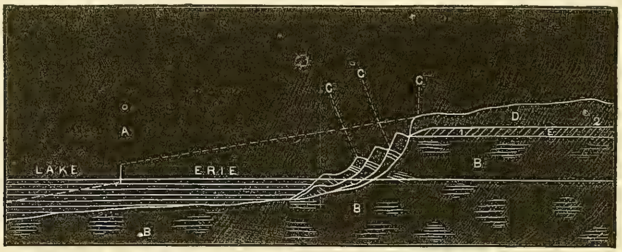
Fac-Simile of a Slab of Niagara Limerock, polished and striated by the drift forces; from beneath the red clay. Sheboygan Light House, Wisconsin.

Between the Menominee and the Peshattego rivers, the country is not elevated, but all the exposed knobs and floors of Sienite are thoroughly smoothed and wrought into domes and hollows by ice action from the north.

Member Number Two.

This division is not so readily made out as the others, but should not be omitted. In the general section I have not attempted to represent it, except in the space between the Apostle Islands and Flag river, of Lake Superior. It will be more apparent in the local sections. In general, this member is thin, passing into No. 1 above and No. 3 below. Its characteristics are, the finer condition of the materials, better stratification, and an alternation of layers of clay and sand.

Fig. 5.



PROFILE ALONG BANK STREET, CLEVELAND, OHIO, representing the slides of October, 1849. A. Ancient shore line. C C C. Present shore line and slides, 1849. B B B. Blue laminated clay. D. Coarse sand and gravel. E. Alternate bands of clay and sand. 1. Position of cedar trees, leaves and springs. 2. Position of Elephant's grinder.

At Cleveland, the grinder and a few bones of the *Elephas Primigenius* were found in D, at a depth of ten feet below the natural surface. The greatest development of the middle member is seen at the Grand Sable, of Lake Superior, east of Grand Island. Here the layers of coarse sand are exposed with a thickness of 300 to 400 feet overlying but a small development of clay. These layers vary from 10 to 50 feet each, having a well-defined stratification. In color, they are bright gray, white, and brown, while their edges cropping out for several miles along the shore, present a more imposing view than the Pictured Rocks. On the summit there is a large tract of treeless and barren dunes, with here and there a clump of pines, nearly covered up by the drifting sand.

This tract extends southerly across the Peninsula to Lake Michigan, thence across Lake Michigan and down its eastern shore. The "Sleeping Bear" and other prominent sand mountains and dunes on that coast, extending as low as Michigan City, belong to this member of the drift formation.

Member Number Three.

The ash colored, the red, and the blue laminated clays, of the general profile constitute this member. A slight difference in the ingredients causes a material difference in their color. The principal cause is the variable proportion of oxide of iron, and its chemical condition. There have not been many analyses of these clays, but the few I am able to give, show that the materials are similar at quite distant points. They are really not clays, but finely comminuted sand, marl, and

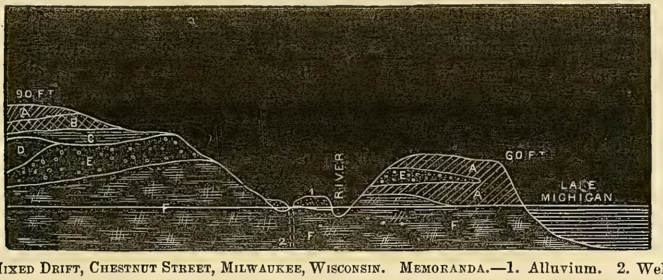
oxide of iron, with alumina enough to cause adhesion. In the valley of Rainy lake river and its tributaries, the color resembles that of ashes, but a little darker. It is the same on the headwaters of the Mississippi, as low as the Crow Wing river, and on the upper waters of the St. Louis river, which discharges itself into Lake Superior at the west end.

On the summit lands, where the streams flowing northerly into Hudson's bay, southerly into the Gulf of Mexico, and easterly into Lake Superior, have their rise, all the members of the drift formation are developed. No. 3 occupies the lower levels, and becomes more conspicuous as we descend those streams from the height of the adjacent land.

The elevation of the summit region is not great, nor is the country broken. Most of it is level and swampy, attaining a height of only 1500 to 1800 feet above the ocean. It is well described by Nicollet as a region of rocks, swamps, and water. The Mesabi Range, which is crossed, in passing from the St. Louis to the Vermilion river, a tributary of Rainy lake, is rather the termination of a rocky plateau, than a regular chain of mountains. In descending the St. Louis river, the ash-colored drift clay of the Embarras and Savannah rivers, assumes a more purple hue, near the mouth of the Savannah.

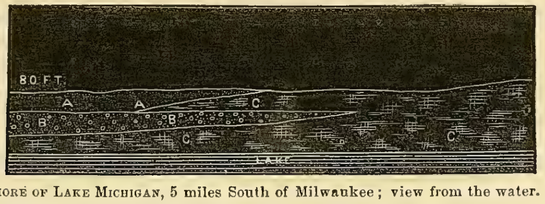
The purple graduates into red, between this point and the Knife rapids, and becomes entirely red on the Grand Portage. The red extends along the shores of Lake Superior to St. Mary's, and to Lake Huron. It is found on all the tributaries of Lake Superior which flow into it from the south up to their sources, and beyond the summit on the streams that run southerly into Lake Michigan.

Fig. 6.



Beds of Mixed Drift, Chestnut Street, Milwaukee, Wisconsin. Memoranda.—1. Alluvium. 2. Well 90 feet in Clay. A A A. Red clay and red hardpan. B. Yellow sandy clay. C. White and purple clay. E E. Gravel. D. Mixed colors. F F F. Blue laminated clay, passing into purple hardpan.

Fig. 7.



Drift Bluffs, Shore of Lake Michigan, 5 miles South of Milwaukee; view from the water. A. Yellow sand and gravel. B B. Coarse gravel. C C C. Purple hardpan passing into red clay.

On Lake Superior, the clay beds attain their greatest thickness. Following the shores of Lake Michigan towards the south, another change takes place in color, from bright red to purple, and finally to blue. These changes are not sudden, but pass into each other by degrees, generally in the form of wedge-shaped layers, which taper out each way as represented in the sections at and near Milwaukee, Wisconsin. Where the change takes place on the St. Louis river, the ash-colored portions on the north predominate. Lower down, the red layers gradually prevail until finally the purple and ash disappear. The same occurs on the shores of Lake Michigan, where the red is passing into the blue. On Lakes Erie and Huron the blue is almost universal, at some places inclining to yellow, as may be seen on the St. Clair river.

There is generally a layer of gravel or sand between the drift clay and the rocks on which it reposes. It is this thin bed of porous materials which furnishes the water to Artesian wells. Water is also found in sandy layers in the clay. The clay bed above and the clay or the rock below being impervious to water, retain that which belongs to the porous layers.

Where the rock bed is limestone, the gravel interposed between it and the drift clay is principally derived from fragments of the limerock, and gives rise to hard water. Artesian wells have been sunk through the clay around Lake Winnebago and Green Bay, and also at Detroit and Toledo. Sections of the strata passed through will be given hereafter. Everywhere in these clays there are to be found small pebbles of the northern rocks and occasional boulders. The pebbles and boulders are marked, polished, and striated, like the rocky basis on which the drift rests. Over all the space through which the section extends, wherever the rocks are hard enough to retain the glacial markings, they are found to be very distinct.

The trap formations of Isle Royal Point, Kewenaw, and Marquette, show the effects of this universal scouring process more perfectly than granite, sienite, or the Azoic slates. On portions of the conglomerate of the trap system, the marks are well preserved, especially upon the close-grained trap pebbles and boulders, which enter into the conglomerate layers intercalated with the trap.

Most of the Potsdam sandstone is too soft and too easily weathered to retain impressions made so many ages ago. Where the glacial movement was parallel, or nearly parallel with the strike of the strata, sandstone beds lying between those of trap as at the east end of Isle Royal, have been carried away to a considerable depth, leaving long narrow promontories and ridges which were better able to resist the grinding process. In this way the contour of the shore and the topography of the country depended upon the hardness of the rocks. On Lake Superior the direction of the arrows of the accompanying map shows that the movement was from northeast to southwest. The trap uplifts of both shores have the same general direction, which also determined the strike of the sedimentary rocks.

This coincidence has had a powerful influence upon the formation of the basin of the lake, which is partly due to the excavating power of the drift forces. The basins of all the great North American lakes and many of the smaller ones have been modified in this way since the last disturbance of the strata. Further reference to this branch of the subject will be made in this paper.

Analyses of the Drift Clay.

BLUE.

Cleveland, Ohio.

Insoluble in hydrochloric acid, silex, and alumina,	77.50
Carbonate of lime,	6.00
Carbonate of magnesia,	9.50
Sulphide of iron,	3.50
Vegetable matter and loss,	3.50
	100.00

RED.

Bad River, Lake Superior. (Dr. Owen.)

Silex,	46.60
Alumina,	17.50
Iron,	10.70
Lime,	5.40
Magnesia,	3.30
Carbonic acid,	7.00
Potash and soda,	3.20
Water,	5.50
Loss,	0.80
	100.00

Copper Boulders and Nuggets in the Drift.

Pieces of native copper torn from the veins of the Lake Superior rocks, being nearly pure metal, resisted the crushing and grinding process longer than any variety of stone. They entered into the mass of the drift, and were transported long distances southward. Those near the mineral range are very large and not much rounded by attrition.

The copper rock weighing 3000 pounds found in red clay on the west fork of the Ontonagon river, and exhibited in the yard of the war office at Washington, and now a conspicuous object in the Museum of the Smithsonian Institution, is an example of these boulders. One was found in 1845 opposite La Pointe on the main land, weighing 800 pounds. About three miles south of the Minnesota mine, on the middle fork of the Ontonagon, another was taken from the red clay that weighed between 300 and 400 pounds.

Another was discovered on the shore of the lake near Elm river, of several hundred pounds weight, by Prof. Shepherd, which is now in the cabinet of Yale College. Farther south they have been found on the waters of Lake Michigan, and Lake Erie, their weight diminishing in proportion to the distance over which they were carried. In a well at Madison Wisconsin, one was found at a depth of 20 feet, weight thirty pounds. I saw one of 3 or 4 pounds weight from drift gravel near the mouth of the Menominee river of Green bay. In Walworth county, Wisconsin, near the south line of the State, a boulder weighing forty or fifty pounds was taken from the drift in a well. One of the size of a "man's fist" is reported to have been found in making a railway excavation at Ada in Kent county, Michigan. I have also seen notices of pieces of native copper in gravel at Ripon and Kenosha, Wisconsin. On the Oconto river of Green bay a nugget of four pounds was found many years since, and a much larger one on the Pensaukie river near the mouth. Small masses are common in the drift of Lake Superior. But the most southerly piece I know of is from Weymouth, Medina county, Ohio, thirty miles south of Lake Erie, and now in the possession of Prof. Brainerd, of Cleveland. These are true "float mineral," indicating, on a large scale and at great distances, the presence of mines in the direction from which they came.

Local Sections and Details.

The profiles I have made or have been able to procure, show much local variety, but at the same time a general correspondence. As most of them exhibit the three members above described in general terms, I present them here under a separate head. One of the first characteristics, and one which demonstrates the unity of the fresh water drift of the northwest, is the presence of buried timber, roots, leaves, and vegetable matter. Mr. Lesquereux, who has examined many of my specimens, is positive that none of them were deposited from salt water. There is no instance of a marine shell among those of my collection.

The timber, as will be seen, is similar throughout the formation, and thus becomes of palæontological value, as well as the shells. The vegetation entombed in the drift extends to all its members. It will be seen that only the vegetation of the present era in northern latitudes is represented. There must have been growing contemporaneously with the drift movement, or prior to it, the same trees that now flourish in northern climates.

Among the exhumed trunks, the white cedar is most abundant; but there are also pine, spruce, willow, and other varieties not fully determined. Most of the bones of the mastodon and elephant found within the limits of my observations, belong to the alluvion or to the modified valley drift, but there are also cases where these relics are found in the true glacial drift. I shall show, before I close, that the drift period graduated into the alluvion so gently that it is difficult to draw the dividing line.

Drift Sections.

ARTESIAN WELL, COLUMBUS, OHIO.

Surface 215 feet above Lake Erie and 780 above tide.

1. Soil	4 feet.
2. Sand, gravel, and boulders	10 "
3. Coarse sand	2 "
4. Blue clay and boulders	4 "
5. Fine quick sand	2 "
6. Blue clay (inclosing a log)	17 "
7. Hardpan	3 "
8. Quick sand	1 foot.
9. Hardpan to cliff limestone	37 feet.
	80 "

COVENTRY, SUMMIT COUNTY, OHIO.

544 feet above Lake Erie, and 1109 feet above the ocean. (By Dr. NEICE.)

1. Yellow sand and clay	22 feet.
2. Blue clay and sand	12 "
3. Gravel and small boulders	4 "
4. Muck and branches of trees from which specimen No. 2, of catalogue was taken	4 "
5. Gray sand 6. Coarse gravel with a great variety of pebbles 7. Sand and gravel	23 "
	65 "

Artesian Well, Toledo, Ohio.

Near lake level. (Dr. J. B. Trembly.)

1.	Yellow clay	20 feet
2.	Blue clay	80 "
3.	Blue clay with small boulders, in which a flow of water was obtained to upper silurian limerock	15 "
		115 "

Detroit, Michigan, Artesian Well, corner of Fort and Wayne Streets.

36½ feet above river level. (A. E. Hathan, Esq.)

1.	Soil	10 feet.
2.	Yellowish marly clay	118 "
3.	Beach sand with coarse gravel to upper silurian limestone	2 "
		130 "

Oak Island, one of the Twelve Apostles Group, West End of Lake Superior.

Summit 300 feet above lake level.

1.	Coarse boulders	15 to	20 feet.
2.	Coarse stratified yellow sand	35 "	40 "
3.	Alternations of red clay with layers of small boulders	25 "	25 "
4.	Coarse sand, red and gray	20 "	20 "
5.	Alternate bands of red clay and gray sand	50 "	75 "
6.	Red homogeneous laminated clay with a few pebbles and decayed leaves resting upon red Potsdam sandstone	100 "	150 "
		245 to	330 "

Green Bay, Wisconsin, Artesian Well.

A few feet above lake level. (Mr. A. Curtis.)

(Cedar log 50 feet from surface.)

1.	Red clay	72 feet.
2.	Quicksand filled with water	3 "
3.	Compact hardpan	6 "
4.	Red clay	1 foot.
5.	Hardpan	4 feet.
6.	Red clay	1 foot
7.	Hardpan	½ "
8.	Red clay to surface of Trenton limestone	20 feet.
		107½ "

Specimens of Buried Timber from the Superficial Materials of the Northwest.

1st. *Ross County, Ohio.*—Apparently cedar mineralized by sulphide of iron, black, brittle, gives the odor of rotten wood when burned, leaving iron rust and ashes. From a well in clay 30 feet deep, 150 to 200 feet above the Sciota river, about 1,000 feet above ocean level. (From Col. Madeira.)

2d. *Coventry, Summit County, Ohio.*—Resembles Osage orange, hard, well preserved, and natural; color dark brown, 42 feet beneath the surface in a well, 544 feet above Lake Erie. (From Dr. Neice.)

3d. *Dover, Cuyahoga County, Ohio.*—Apparently cedar, fine grained, partially rotted, not mineralized, among several other sticks more or less rotted, and frag-

ments of shells and leaves, 12 feet below surface and 153 feet above Lake Erie. (From Dr. Moore.)

4th. *Cleveland, Ohio.*—The entire trunk of a white cedar 20 feet in length, with the roots and a part of the branches, the bark and knot-holes filled with protosulphide of iron, 50 feet above Lake Erie and 18 feet below surface. (From Mr. John Wills.) This and many other fragments of timber lay in a muck bed between the gray sand of the section and the blue clay.

There are in this layer an abundance of the leaves of the pine, spruce, and cranberry. Many wells in the city are rendered unfit for use by this layer of vegetation. The springs that issue from the bank of the lake are chalybeate, and deposit iron rust. In the clay below, and the blue clay generally, are thin black streaks of carbonaceous matter, resulting from the leaves. Some of the pieces of wood are well preserved, and are water-worn by attrition, in the same manner as the drift wood of the present beach of the lake.

5th. *Hamilton County, Ohio.*—Of 59 wells which I examined in this county, six had muck beds, leaves, timber, or silt. Their elevation ranges from 300 to 500 feet above the Ohio river, or 150 to 350 feet above Lake Erie. They are situated near the southern limit of the northern boulders.

Section of Wells near Carey's Academy.

7 miles north of Cincinnati on the height of land.

1. Surface clay and loam	18 feet.
2. Yellow sand	0 " 2 inches.
3. Blue marly clay	1 foot.
4. Leaves and sticks	0 feet 2 "
5. Vegetable mould	3 "
6. Vegetable mould and marl	6 "
	28 feet 4 inches.

At about the same elevation, near New Burlington, in the same county, in three wells not far from each other, the diggers found what they call "grape vines," or a mass of leaves, trees, and muck. From one of the wells, a log one foot in diameter was taken. There was frequently so much vegetation as to ruin the water for drinking. Three miles north of New Burlington at a lower level by about 200 feet, a layer of logs was found at 30 feet from the surface.

In another well, a bed of leaves and logs under blue clay was passed at 40 feet. Another gave the following section:—

1. Surface loam	1 foot.
2. Yellow clay	3 feet.
3. Sand	2 "
4. Blue clay	14 "
5. Leaves and sticks	
	20 feet.

Thirty-five of the fifty-nine wells of this county, about which reliable information could be obtained, had layers of blue clay. The logs, leaves, and sticks, were always in the clay beds, and the blue clay invariably below the yellow.

Mr. David Christy, of Oxford, Butler county, Ohio, has described an upright stump and roots of a tree in the blue clay, eight miles east of Oxford, at a depth of thirty feet. Dr. Hildreth notices several instances of logs in the blue clay of Athens county, Ohio, some of them 40 feet below the surface.

At Mercer, Ohio, near the source of the Little Miami river, timber and dirt beds are known at a depth of forty and fifty feet. In numerous instances, half decayed logs have been found in the wells of Scioto county on the upland farms, 200 to 400 feet above the Ohio river. The same has been observed in the counties of Madison, Franklin, and Stark, showing that muck beds and trees are universal beneath the soil throughout Ohio.

6th. *Walworth County, Wisconsin.*—Resembles white cedar, decayed but not decomposed; color bright, not mineralized, from a well eighteen feet deep in a prairie region, about 250 feet above Lake Michigan. (I. A. Lapham, Esq.)

7th. *Appleton, Wisconsin.*—Juniperus Virginiana (red cedar) in red clay eighteen feet below surface, about 150 feet above Lake Michigan, not rotten nor materially changed; another specimen, apparently white cedar, thirty feet below surface in same red clay somewhat decayed. (From Dr. S. E. Beach.)

8th. *Green Bay, Wisconsin.*—Apparently willow in red clay fifty feet below the surface of Lake Michigan, well preserved. (From Daniel Whitney, Esq.)

9th. *Banks of the Embarras River, Minnesota.*—White cedar ten feet below surface at base of a sandy layer near the Mesabi range, about 600 feet above Lake Superior.

10th. Two logs of resinous timber are reported by the Hon. Chas. Mason to have been found in a well 60 feet deep at Iowa City, Iowa, on the upland or general level of the country. A bed of sticks and leaves was observed by the same gentleman at Burlington in the same State, 100 feet above the Mississippi river, at a depth of 12 feet.

Animal Remains of the Drift.

The elephant and mastodon of the drift era survived till the period of the alluvion proper. Many years since, the grinder of a mastodon was found on the west side of the Cuyahoga river, at Cleveland, in the valley alluvion, near the lake level, resting upon drift clay. The Bucyrus Mastodon, the skeleton of which is nearly perfect, was imbedded and preserved in swamp muck and marl. It is described in the *Ohio Reports* for 1839. A tusk of the elephant and other bones, exposed at the railway cut, near Sandusky, Ohio, were in a recent bog. Grinders and bones of the elephant have been found in the modified or valley drift, beneath the city of Cincinnati. I have seen the same in alluvial muck in Ross County, Ohio, about 50 feet above the bottom lands of the Scioto valley.

The Big Bone Lick, of Kentucky, is within the range of extreme high water of the Ohio river, partially covered by the fine yellow loam-like deposits of that stream. The Castoroides Ohioensis of Mr. Foster, belongs to the modified drift of the valley of Licking river. The same gentleman discovered the grinders of an elephant in the valley drift of the Muskingum river. But there are also cases

in considerable number where the remains of the mastodon and elephant must be referred to the more ancient beds of the unmodified glacial drift, and even to the tertiary of the Mississippi valley.

The well preserved mastodon at Aurora, Illinois, was imbedded in a recent swamp. Mr. Morris Miller, of Hanoverton, Columbia county, Ohio, is in possession of the grinder of a horse, and the tooth of a bear, which he found in a position that he considers to be on the true drift. In the valley-drift of Yellow creek, in the same county, Mr. E. White, C. E., took from a cut on the Cleveland and Pittsburg Railroad at a depth of 30 feet, the jaw of a pachyderm, which was exhibited at the Cincinnati meeting of the American Association, in May, 1852.

On page 218 of Prof. Emmon's "Manual of Geology" is a figure of the crown of the grinder of a horse, taken from the Post Pliocene beds of North Carolina. I have a tooth from the compact marine drift of Long Island, taken by J. A. Bailey, Esq., from excavations at Fort Schuyler, at Throg's Neck (18) eighteen feet below the surface; specifically identical with that figured by Prof. Emmons. Another one is before me, procured by Morris Miller, Esq., in the valley of Sandy creek, Columbiana county, Ohio, 530 feet above Lake Erie. It was thrown out about twenty years since in making the Sandy and Beaver canal, in connection with bones of the mastodon. Their depth cannot be fixed, but could not have exceeded twelve or fifteen feet. The material is a modification of the fresh-water drift, not far from the southern limit of the boulders, belonging, therefore, to the most ancient alluvium.

In this position most of the bones of the mastodon have been found, while those of the elephant are often seen in the unmodified drift. It is the same with the Castoroides Ohioensis and the tapir-like jaw of Yellow creek. Joseph Sullivant, Esq., of Columbus, Ohio, many years since obtained from the crevices of the Cliff limerock on the west bank of the Scioto river at that place a number of bones imbedded in red clay. One of them he regarded as belonging to the Hippotherion. Among them was the grinder of a horse, which unfortunately has been mislaid. The crevice had not been open since the date of the white settlement of the country, and was wholly filled with the compact red clay which results from the decomposition of limestone containing iron and filtration. A layer of the ordinary drift materials of the region, apparently undisturbed, lay over it several feet thick.

Shells from the Drift and other Superficial Materials of the Northwest.

Cleveland, Ohio.—Helix arborea, Helix solitaria. Blue clay twenty feet above Lake Erie. Helix fallax, upper and yellowish portion of the clay. Helix striatella [or omphalus], 40 feet above Lake Erie. Fragments of Melania said to have been found 100 to 120 feet above the lake, at the base of the sand ridges.

Milwaukee, Wisconsin.—Planorbis campanulatus, Paludina decisa, Melania depygis, Lymnea desidiosa, Cyclas similis. Twelve to twenty-four feet above lake level, in yellowish compact clay and hardpan.

Dubuque, Iowa.—Two varieties of Cyclas, one crenated resembling Castalia, in the Loess-like loam, 150 to 180 feet above low water in the Mississippi. Lymnea

decidiosa, 15 to 30 feet below the surface, same elevation as above. Also a fragment of Planorbis in red clay, 60 feet above the river, and 580 to 700 feet above the ocean.

Near Peoria, Illinois.—Helix concava, Helix chersina, in coarse sand and gravel beds, 120 feet above Illinois river.

Seven Miles East of St. Louis, Mo., River Bluff.—Helix alternata, Helix striatella, Helicina ———? Amnicola ———? Lymnea valvata, Succinea obliqua, in Loess-like loam; with calcareous concretions, 30 to 40 feet below surface, 150 to 200 feet above low water in the Mississippi river and 500 to 580 feet above tide.

New Harmony, Indiana.—Helix hirsuta, Helix fraterna, Helix minuta, Pupa ———? (New Species) Amnicola? Lymnea decidiosa, in Loess-like loam 50 to 100 feet above the Wabash river.

For the names of these shells I am indebted to Prof. Agassiz and Dr. J. S. Newberry.

Ancient Terraces and Ridges.

Throughout the western country there are bluffs and terraces, which are composed of solid rock, and which are due to geological causes, more ancient than those under discussion. In some cases the boldness of rocky terraces has been toned down by the drift forces, as well as by the disintegrating power of the atmosphere.

Terraces due to drift action are composed of boulders, gravel, hardpan, and clay or sand. In most cases they represent an ancient shore. During the period of emergence, where the water line remained fixed long enough to allow the waves to cut into the slopes of the shore, a steep bluff was the necessary result.

The following plan and profile at Cleveland, Ohio (on page 26), illustrate the changes that have taken place there in soft strata by wave action alone. If the clay bluffs on the present shores of the lake were no longer undermined by the waves, terraces would be formed. Suppose by a depression in the outlet of Lake Erie, its surface should fall rapidly thirty feet. The present shore line would forever mark the present level of its waters. An ancient shore can be traced, in the form of a terrace, on the south shore of this lake, from near Erie, in Pennsylvania, to the Vermilion river, in Ohio, a distance of about one hundred and twenty-five miles. It is nearly parallel to the coast, and its base is about one hundred and sixty feet above water level. On Lake Superior there are many such terraces well defined.

The most conspicuous of these may be seen on the highlands, southwest of Bayfield, Lake Superior, opposite the Apostle Islands. Here there are four, the lowest of which has its upper surface from 100 to 120 feet above water level, and the fourth or highest 400 to 430 feet.

What are commonly known as "Lake ridges," are, it seems to me, not due to the same cause as the terraces. They are not ancient beaches, but the result of lateral currents such as in all waters cause subaqueous bars and spits, rudely parallel with the shore. Their composition is universally coarse water-washed sand, and fine gravel. Around Lake Ontario on the Canada side, Sir Charles Lyell and Mr. Ray found traces of eleven of these ridges more or less parallel with the present

shore line, the highest being 680 feet above its surface or 912 above tide. Prof. Hall has described five of them on the New York side of the lake, the highest being 762 feet above Lake Ontario or 1090 above tide. In Ohio I have noticed but four regular and continuous ridges. There must have been others at lower levels now carried away by the advance of the shore line. In Michigan, they have been noticed within thirty feet of the lake level.

The first or nearest one to the lake is the most regular. I have its elevation at or near the base, at twelve points along a line of seventy miles from the Conneaut to the Black river. The height varies from sixty to one hundred and five feet. It is very regular and continuous, and used most of the distance as a public highway, ready formed by nature for the use of man. Its height above the base varies from fifteen to twenty feet.

Occasionally the summit of the ridge is broken into sand knolls of about the same height, which may be seen at Painesville, Cleveland, and Avon. The lowest summit of the ridge is eighty-five feet, and the highest one hundred and forty-five, showing a difference of level longitudinally of sixty feet. This corresponds with one in Washtenaw county, Michigan, which is about 140 feet above the lake. Terraces due to an ancient shore line should be at the base nearly level. The country on all sides slopes gradually toward the lake, so that the interior ridges overlook those between them and the water. All the rivers and streams of the region cut the ridges and the drift clay, frequently down to the rock below.

Between the ridges where they are within a short distance of each other, there are long narrow swamps which drain laterally into the streams. The height of the second ridge in Ohio varies from 122 to 168 feet in a distance of 60 miles, the greatest difference of level being 46 feet. The third and the fourth ridges are not so well defined.

Some points on the fourth ridge between the Cuyahoga and the Black rivers, have an elevation of 173 to 203 feet. Around the west end of Lake Erie and on the Canada side, they have been observed, but their altitude is not known. Like submarine bars now forming, these have branches and spits, which sometimes run across obliquely connecting two parallel ridges. Ancient lake ridges must not be confounded with "lake beaches" which were formed afterwards, by the action of the waves upon the shingle of the shore.

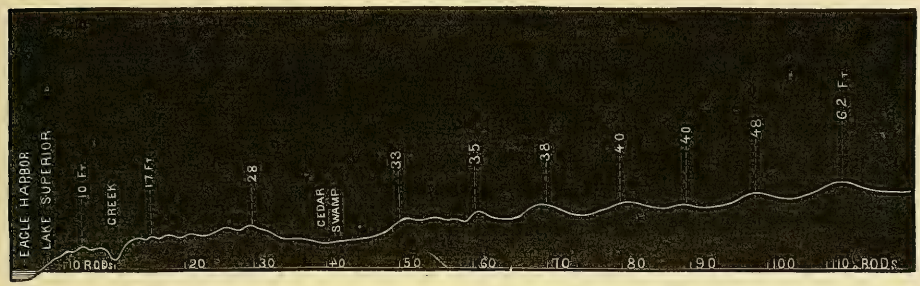
On the north shore of Lake Michigan, there are remains of such beaches, composed of gravel, and others around the south end of the lake composed of sand, which are quite ancient, considered with reference to historical epochs, but which belong to the alluvium. The surface of all the lakes has settled away, and is now settling away in a very gradual manner, by the wearing down of their outlets.

Beaches of water-washed sand, and shingle, as perfect as those now forming, are seen rising in succession behind each other; on Lake Michigan as high as eighteen and twenty feet. There are in some places four of them within fifteen or twenty rods of the present water-line. A more extended reference to this class of ridges may be seen in Foster and Whitney's Report on the Geology of Lake Superior, Volume 2, Chapter 16.

On Lake Superior the recent beaches are composed principally of sand. They

have been observed at various elevations up to eighty feet, which corresponds closely with the surface of the drift across the valley of the outlet of this lake at St. Mary's. At Eagle harbor there are eight of them within a distance of one hundred and ten rods, as represented in the accompanying profile. They may be seen around the head of Green bay, within twelve to fifteen feet of lake level, containing the same shells which now inhabit the waters of the bay. The distinctive feature of the alluvial beaches, as compared with lake ridges, is that the former are narrow and are steepest on the lake side, resembling miniature terraces. The materials are also different, being not distinguishable from the clean beach sand and shingle of the present water line

Fig. 8.



PROFILE OF ANCIENT LAKE BEACHES, EAGLE HARBOR, LAKE SUPERIOR.

In the prairie region of Illinois, Wisconsin, Iowa, and Missouri, the general surface is very uniform, and but little elevated above the northern lakes. A rise in Lake Michigan of twenty-six feet would turn its waters across the summit into the Illinois river. The country around Elgin on the Fox river of Illinois, is from one hundred and sixty to two hundred feet above this lake, or seven hundred and fifty to nine hundred and ninety above the ocean. Around Galena the summits of the hills are seven hundred and fifty to nine hundred and ninety feet above tide.

The rolling prairie opposite St. Louis in Illinois is not materially different, and is nearly on a level with the region above Peoria. This general level stretches away up the Missouri river to the northwest corner of the State of Missouri, and up the valley of the Desmoines in Iowa to the centre of that State. The central parts of the lower peninsula of Michigan rise only seven hundred and fifty to eight hundred and fifty feet above tide, and the summit between the Maumee river of Lake Erie and the Wabash, is between those figures. On the east the Alleghany mountains from Alabama to New York, rise from two thousand to six thousand feet; but in the valley of the lakes the way is open eastward to the ocean.

The rocky strata around the east end of Lake Erie present no barriers, since they rise but a few feet above the lake level. Between Lakes Erie and Ontario the present surface of the drift rises no higher than ninety feet above the mean level of Lake Erie. The Erie canal is fed from Lake Erie by a moderately deep cut in drift and rock, carrying the same level to Lockport on the bluff facing Lake Ontario. Between the Georgian bay on Lake Huron and Lake Ontario, the summit is occu-

pied by Lake Simcoe, reported to be four hundred and fifty feet above Lake Erie, or one thousand and fifteen feet above the ocean.

Mr. Lyell states that there are from Lake Ontario up to this summit well-defined "lake ridges," eleven in number. On the south there is in the present conformation of the country a broad outlet in the Mississippi valley reaching from the western spurs of the Cumberland mountains to the eastern outline of the Ozarks. In this depression the tertiary beds are deposited, rising only two hundred and fifty to five hundred feet above tide water. The great cretaceous and tertiary formation lying to the east of the Rocky mountains is much more elevated.

Over a territory embracing the States of Ohio, Indiana, Illinois, Iowa, and parts of Kentucky, Tennessee, Missouri, Wisconsin, Michigan, and Canada West there are no mountains. This space is a flat basin with a rolling surface, the highest parts of which rise only seven hundred to twelve hundred feet above the ocean. A horizontal plane at one thousand feet elevation would cut off very few of the summits, and those beneath would be but little below it. There are valleys of erosion, cutting all the strata, from the valley drift to the Potsdam sandstone, but no upheavals.

The accumulation of ice over so large a space on the earth's surface could have taken place only from the atmosphere, at the slow rate of a few feet in a year. Its disappearance upon a change of temperature should be equally slow. In addition to the flat surface of the country, this mixed mass of ice, sand, and gravel obstructed the flow of the retiring waters.

In this way, a long time must have intervened between the glacier period and the reappearance of the soil, during which changes of a mixed character were going on. In some parts of the field there were glacier movements, while in others there were aqueous movements only. The tertiary of the Mississippi valley extends northerly to Cairo, at the mouth of the Ohio.

On account of a similarity in external appearance between the northern edges of the tertiary and the more recent beds of clay, sand, and gravel, it is not practicable to fix their limits or superposition without further examination. Between the northern limits of the Mississippi tertiary and the southern edge of the glacial drift, there is in Ohio, Kentucky, Indiana, and Illinois, a belt of debatable ground, the outlines of which are not easily defined.

Before the glacial period, the general configuration of the surface of the Northwestern States must have been essentially what it is now. The position of the valleys of the great rivers and lakes were about the same as at present. In the general elevation of the entire region there may have been changes, but these were of so extensive a range as not to disturb the local relations of the surface.

As the rocks had not then been subject to the grinding process of the drift forces, the superficial materials must have been much less in quantity, and of a much finer quality than they are now. The rocks were decomposed and disintegrated solely by atmospheric and chemical agencies.

The mechanical power of immense fields of ice, in places several thousand feet thick, moving slowly over the surface of the land, from about the latitude of 40° north to the Arctic circle, had not then crushed and pulverized the exposed parts

of the rocky strata. This movement, enduring for a long period of time, served to remove a large portion of the broken fragments of the northern rocks to regions farther south; leaving, at its close, the strata towards the pole bare, or with less earthy covering, and those south of the Arctic circle with more.

As the glacial era drew towards its close, the transporting force changed from one in which ice predominated, to a modified movement of ice and water, which, of course, affected the condition of the materials. They show everywhere the effects of two kinds of force. Sometimes, especially upon and north of Lake Superior, the unstratified, confused drift, with coarse gravel and boulders, and the stratified water-washed sand, clay, and gravel are in close connection.

Towards the south the materials are finer, and a larger proportion stratified. Beyond the coarse boulder portion and the striated rocks, the proportion of finer materials predominates. These beds are composed also of clay, loam, sand, and gravel, due to this modified form of deposition. In Southern Illinois and in Missouri the prairie land commences towards the south on these deposits.

The prairies are not, however, confined to them, but extend northerly into Wisconsin and Iowa, over the true drift regions, and westerly and northwesterly over the cretaceous and tertiary formations, showing that the treeless country is not wholly due to geological causes.

Earth thrown out of the wells of Ohio and the mineral pits of Wisconsin, immediately sends up weeds, grasses, and shrubs that appear to come from seeds preserved in the drift beds. Where timber is so well preserved below the effects of the atmosphere, the seeds of plants might well retain their vitality.

As to forest trees, their germs would be of varieties belonging to an Arctic or subarctic climate, brought southward out of their proper place, and would not flourish well in their new position. The southerly portions of the drift, and the superficial beds between it and the tertiary strata of the Mississippi valley, have more loam and clay, with less sand and coarse gravel, than the northern drift, which form a rich soil, stimulating to annuals and grasses. When vegetation became again prolific, the surface of the country along the southern edge of the glacier regions must have been a long time flooded with water and floating ice, the motion of which would also be towards the south. In the central parts of the continent this water would be fresh. The leading valleys would bear away the largest portion, and the currents thus produced would be most powerful along the valleys. For a time there would be a mixture of ice, water, boulders, gravel, and mud, in a fluid or semifluid state.

In this way the finer materials were transported farther to the south, and scattered there after the glacier motion had ceased. The northwestern States are so little elevated, that large portions of the upland would be for a time submerged, over which the finer sediments were dispersed. Immense floes of moving ice, grounded upon the higher lands with currents between, would produce many of the effects we witness.

The unstratified hardpan, and the half-worn and striated fragments of adjacent rocks, convey to an observer evidence of pressure and mechanical forces wholly inexplicable by hydrostatic action. When the thawing agencies commenced, the

liquid part would find its way to the lowest ground, forming local basins of water; and as these increased, the buoyant force would be competent to raise and float the solid portions.

As the watery portion increased and began to predominate, there must have been general currents, as there are in all large bodies of water. Thus the sorting and stratification of the finer materials can be accounted for. For a time the glacial waters would be muddy, and thus the lighter sediment corresponding to the prairie loam could be transported and deposited over large tracts.

It is to this period of moderate southerly currents that I ascribe the loess-like deposits of Illinois, Southern Iowa, and Missouri. The preglacial valleys formed a convenient receptacle for these materials in their southerly progress.

As the recent rivers began to assume the channels of a prior geological era, they cut down rapidly into the soft materials, which were thus again transported to lower levels, forming alluvial deltas of which the one at the mouth of the Mississippi is the most conspicuous. This is the epoch of river terraces.

Glacial Striæ.

The course of the arrows upon the map is fixed by the following table, showing the bearing of grooves and striæ at numerous points. Where there is more than one observation, groups have been formed by taking the average of several observations whose bearing lay within the same quadrant. The number in each group embraces a certain contiguous territory which is determined arbitrarily.

To mark on the map each observation by an arrow is not practicable on this scale, and would convey a less clear idea than the results represented by groups. Those in States eastward of Ohio are taken from published geological reports.

In the States of Ohio, Michigan, Wisconsin and Minnesota, they are principally from my field-books, making use, in addition, of such as are reported by Prof. Hector of the Pacific Railroad Surveys of Canada, and by Messrs. Foster, Whitney, and Desor.

ABSTRACT OF THE BEARING OF THE STRIÆ.

Field of observation.	Number of observations.	Resultant bearing of the group.
MINNESOTA.		
Dog Lake	1	South 10° west.
Lake of a Thousand Islands	1	South 5 "
Rainy Lake	1	South 50 "
North shore of Lake Superior	1	South 46 "
WISCONSIN.		
Ashland County, Penokie Range	2	South 45° east.[1]
Do. do. near Bad River	2	North and south.
Lake Winnebago and Sheboygan	4	South 45° west.
Valley of Menomonee River	3	South 65 "
MICHIGAN.		
North shore of Lake Michigan	4	South 80° west.
Isle Royal	3	South 40 "
Point Keweenaw and Keweenaw Bay	4	South 38 "
Marquette County	8	South 32 "
OHIO.		
Northeastern Counties	9	South 26° east.
Sandusky	3	South 80 "
Dayton	1	South 26 "
NEW YORK.		
Rochester	1	South 30° west.
Valley of St. Lawrence	Several.	South 45 "
Valley of Hudson River	Several.	South 5 east.
MASSACHUSETTS.		
Valley of Connecticut River	Very numerous.	South $8\frac{1}{4}$° east.
Boston	Very numerous.	South 20 "
VERMONT.		
Canada Line	Numerous.	South 20° west.
Lake Champlain	Numerous.	South 30 east.
MAINE.		
Valley of Kennebec	Numerous.	South 15° east.

So far as this record goes there is a general agreement between the bearings of the drift-striæ, grooves, and furrows, and the course of valleys in which they are situated. The height of the land on the line A B of my section is nowhere so great as it is in New England or on the Alleghany mountains. I know of no points in the vicinity of the section where the land rises much above it. In the northwest, therefore, there are no such marked elevations or mountain ranges as would very much obstruct the glacial movement. But whether the obstruction was greater or less, the direction of the striæ shows that the movement, as was natural, pursued the lowest existing channels. In its general course up the valley of the St. Lawrence the high lands of New England and Northern New York, rising five thousand to six thousand feet above the ocean, operated as a barrier. It found a partial outlet in the north and south valleys of Lake Champlain and of the Connecticut river, while the heights in which the Alleghany mountains terminate, rising eighteen hundred to two thousand feet above tide water, presented another obstruction.

On Lake Superior there is a remarkable uniformity in the bearing of the glacial

[1] In a gorge at right angles to the range.

furrows. One-half of the courses on my list are between south 20 and south 30 west. In the vicinity of the Aztec, the Ohio, and the Adventure mines in the Ontonagon district there are however some exceptions to the general southwesterly motion. I omit these from the general average, because there are disturbing causes in the configuration of the ground that are evidently local. In one case at the Ohio mine the course is south 30° east, but this is in a gorge of the mountain through which the glacier ice was forced as in a channel nearly at right angles to the general movement. Here the vertical walls of the gorge, as in many other places, are worn smooth and striated in the same manner as the floor. These striæ are either horizontal or inclined, so as to correspond with the bottom of the gorge. Where the red clay has been penetrated, in the adit of the Adventure mine to the rock wall of the ravine, the scourings and abrasion of the trap remain perfectly fresh, showing that the surface had never been exposed to the weather.

The gorges here are caused by fractures and dislocations of the trap formation, which constitutes a long, high, bold and narrow range, 800 to 1000 feet above Lake Superior. These sharp summits and cliffs are moutonné like those throughout the trap range of Point Keweenaw.

It is so likewise with the rocks of the iron region of Marquette which are very much worn and scoured down, from the rounded Islets at lake level, to the hard quartz and iron summits 1000 feet above. Messrs. Foster and Whitney observed, near Teal lake, the same markings on vertical faces of the rocks which I have noticed on the waters of the Ontonagon and Bad rivers. The low rocky islands of Rainy lake and of Vermilion lake, are artificially rounded by drift action.

In the New England district ice markings have been noticed at 3000 feet elevation. The glacial mass may have been in that quarter thick enough to rise to the highest summit, but no doubt decreased in thickness towards the southwest. In Ohio the highest land which has well defined polished surfaces and striæ is 1300 to 1400 feet above the ocean level, and the same may be observed on the trap ranges of Point Keweenaw having about an equal elevation of 1400 to 1600 feet.

A less thickness of ice and nevé would therefore suffice at the west to cover the greatest elevations of the country. The southern limit of distinct glacial etchings corresponds very well with the line of dots representing the lowest or southern edge of the large boulders of northern rocks. Water-worn fragments and pebbles of these rocks are seen farther south, but not in such numbers or of such size but that they may have been transported by water alone. The modifications of the drift and other superficial materials below this line are doubtless due to this agent.

Encroachments of the Water upon the Land.

The clay bluffs of all the lakes are easily worn away by the action of springs, rains, winds, and waves. Being more or less marly, and having a large proportion of sand in a finely divided state, water readily dissolves this deposit, and the shore line rapidly gains upon the land.

There is in the drift clay little tenacity or power of support. Where it is attacked at the base and partially undermined, the bank settles down suddenly in

heavy slides, carrying with it trees, buildings, or whatever may be standing upon it. Thin partings of sand near the water level assist in accelerating the process of destruction. The fine materials thus taken from the land are, after a storm, suspended for awhile in the water, which becomes colored and muddy several miles from shore.

In due time they are deposited at the bottom of the lakes, accumulating there as a formation more recent than the drift, but reaching back to the close of the drift period. The section at Cleveland illustrates the changes that have produced this lacustrine alluvium. Lakes Erie and Michigan having a shore in most of its circuit composed of the drift clays, are filling up more rapidly than Huron and Superior, which have more rocky coasts.

This deposit, as indicated by the mud found on a vessel, which sunk in sixty feet water, three miles off Cleveland, accumulates at the rate of more than twelve feet in a century. It embraces the remains of man and of modern art. At the city of Cleveland there exist data for an estimate of the rate of encroachment. The site of the town was surveyed in 1796. In 1842, forty-six years afterwards, the advance of the shore line had been so rapid, that it was necessary to check it by works erected at the expense of the city, and afterwards made more permanent by various railway companies. The encroachment opposite the public square since the survey, had been, at that time, two hundred and sixty-five feet.

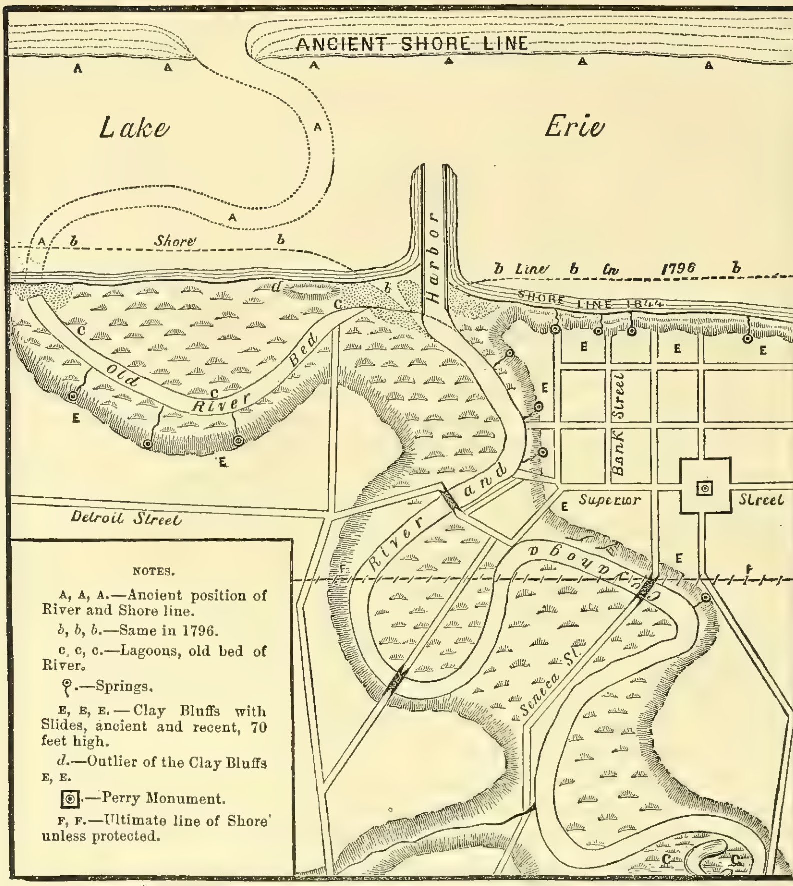
Cleveland stands upon an inclined plateau sloping towards the lake at a rate which would bring the shore down to lake level in about two miles. Since the lake assumed its present level, it has encroached thus far upon the land. Had it continued to advance at the rate of the first forty-six years since the settlement of the city, the coast line would, in about five hundred years, have reached the public square on Superior street, and would have undermined the statue of Commodore Perry erected there.

In 1796 the open mouth of the Cuyahoga river was at *d*, *b*, of the annexed plan. Sometimes the west end of the old river bed was open and sometimes closed. Before the end of five hundred years, at this rate, the mouth of the river would have been at the foot of Superior street, and before the close of one thousand years at F, F, near the Seneca street bridge. Soon after the shore line should have reached Superior street, the bend of the river on Columbus street would have formed a lagoon like those at c, c, c.

On the Canada shore opposite Cleveland the rate of encroachment appears to be as rapid, the height and composition of the shore being about the same. There is in the blue clay a series of joints like those in the indurated rocks. When it is undermined it falls in large blocks, with faces nearly at right angles. If it were metamorphosed and hardened by heat, pressure, or chemical action, it would present the external characteristics of the ancient azoic slates, being thoroughly laminated and jointed. Here the slopes of the shore remained at rest, on an angle of fourteen degrees inclination, but at other points they stand at a much steeper angle. The color of the deposit now going on in the lake must be different from that of the drift clays. On Lake Erie the silt brought down by rivers mingles with the disturbed materials of the blue clay, giving it a more loamy character and a tinge more brown and yellow.

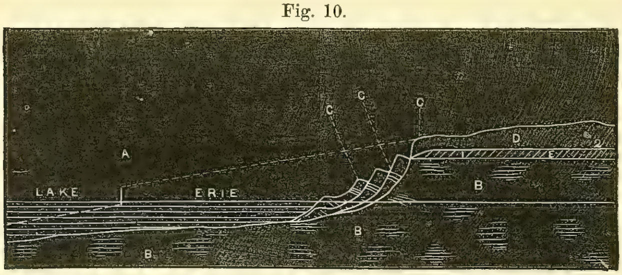
4 May, 1866.

Fig. 9.



Map showing the rate of the encroachments of Lake Erie at Cleveland, Ohio.

Fig. 10.



Profile along Bank Street, Cleveland, Ohio, representing the slides of October, 1849. A. Ancient shore line. C C C. Present shore line and slides, 1849. B B B. Blue laminated clay. D. Coarse sand and gravel. E. Alternate bands of clay and sand. 1. Position of cedar trees, leaves and springs. 2. Position of Elephant's grinder.

Most of the shore of Lake Michigan is sandy, but in part it is of blue, purple, and red clay (see profiles at and near Milwaukee). At Cleveland, some deceased soldiers of the war of 1812 were buried near the margin of the bluff, and in 1836 their remains had already reached the lake level, under the operation of repeated slides. A short time prior to 1796 a British vessel was wrecked within the present limits of the city of Cleveland. There were on board of it some brass field pieces, which were taken out by the captain, and buried on a bench about half way up the bank. These pieces have often been sought for without success. The encroachment of the water line must have reached them in about twenty years, when they would soon settle into the soft clay and quicksand out of sight. The rate of advance is, however, not uniform; it depends upon the character of the materials and the height of the water. By consulting the Smithsonian Contributions for 1860, vol. XII., it will be seen that all the lakes are subject to fluctuations of level varying from five to seven feet. During periods of low water, the wearing action is not rapid. There are times for many years together when there is a beach of littoral sand, along the foot of shore bluffs previously washed by the waves.

The early emigrants to Ohio had the good fortune, from 1796 to 1800, to find a natural road along the beach of Lake Erie, which was soon after submerged. By turning to the profile along Bank street, Cleveland, page 26, the process of undermining and consequent removal of the shore bluffs will be understood. There are no rocks indeed so solid but that the action of the surf destroys them more or less rapidly. Where the shore has no rocky barrier, but only a bank of clay, or of clay interstratified with sand and gravel, the work of destruction is rapid. All the drift clays are marly, and also contain sand in a fine state of division. The water softens, and dissolves these marly clays into a quicksand.

A very slight motion of the water is sufficient to carry away this material, the coarser parts and the gravel remaining on the beach, while the finer parts go to form alluvium at the bottom of the lake. When the undermining process at the water line has reached so far as to destroy the equilibrium of that kind of earth, there must be a slide. The weight of the earth at the summit of the bluff carries it downward in long narrow strips of land, one, two, and three rods wide, according to the height of the shore. This movement, somewhat like a crevasse, pushes the mass of previous slides, C, C, C, forward and downward into the water. Excavations on the sides of the valley of the Cuyahoga river show the fissures of very ancient slides.

The movements are easily traced by the position of the different strata B, C, D, which differ both in color and composition.

A mere line marks the crack along which the slide moved in its descent, unless the waters of the springs enter it, and disintegrate the beds. Some of the fissures are open, particularly at the base of the slides, and some are filled with oxide of iron deposited from solution. We have here cases of faults and dislocations occurring before our eyes, where the opposite surfaces are smooth, and scarcely discernible.

As the red clay is more tenacious than the blue, it stands at a steeper angle, but the coast-line of Lake Superior is gaining upon the land with equal rapidity. The

force of the wave is greater in northern waters than in southern, being more dense. The wind is more powerful, and storms are more frequent. Slides occur there in the same manner as upon Lakes Erie and Michigan, carrying down standing trees and houses. On the waters of Bad river, Ashland county, Wisconsin, slides frequently happen at the high bluff banks, precisely like those in the bends of the Cuyahoga river in Ohio. In the blue, the red, and the purple clay beds there are occasionally inclosed patches of sand and gravel, not stratified; but this is not common.

The sand and gravel are generally in layers between beds of clay, but tapering out in distances of no great length. There are also bunches of clay inclosed in the strata of sand, though such cases are rare.

Boulders Moved by Ice.

Around the borders of small northern lakes, it is not unusual to see a line of boulders compactly arranged at the water level. They are usually too large to be moved by the action of waves, and are pushed up along the shore, so as to present from the water the appearance of a rude wall or fence composed of rounded rocks.

More than fifty years since, President Dwight, of Yale College, described the movement of boulders towards the shore in a small lake in Salisbury, Connecticut. I once examined the place in company with the late Professor Averill, of Union College, who lived in the vicinity. He had often observed them near the shore, and near the surface of the water, and was satisfied of their motion towards the land.

Where the top of the boulder was within a foot of the surface, there was a distinct groove behind it, its direction being in a right line for the land. In front of it the mud was pushed up, showing that it had been forced in that direction. We concluded that the ice in winter was equal to one foot in thickness, and generally more.

As in all bodies of water, there is here some fluctuation of level. Ice a foot thick or more would envelop the upper part of the boulders in shallow water, and extend down around them below the general thickness. The increase in bulk by freezing must take place from the centre outwardly, and thus create a slow but powerful motion at the edges towards the shore.

Lines of boulders may be seen on the banks of the St. Lawrence, between Montreal and Quebec, pushed against the shore in part by the expansion of fixed ice, and in part by masses of floating ice. There is in Iowa a small lake, which is belted by so strong a line of boulders, that it was at first supposed to be an artificial fence or wall of stone, and which has thence taken the name of the "Walled Lake."

On the shores of Mille Lac, which is at the source of the Rum river, in Minnesota, and which is about twenty miles in diameter, there are very heavy lines of large boulders, rising five and six feet above water-level. There are also several small islands in this lake, at different distances from the shore, composed entirely of large boulders, generally more than two feet in diameter, which have accumulated in the same way with those on the shore. One of these has a height of twelve

or fifteen feet, wholly free of gravel or earth. They are from one to four miles from the shore, and in shallow water. The boulders are sienite, granite, trap, gneiss, &c., being the same with those which occur in the drift beds of the adjacent shore.

As the degradation of the land goes on the number of stones increases, and the line becomes more conspicuous. In those northern latitudes the ice attains a thickness of two and three feet; thus reaching down to boulders which lie in five and six feet water. In a low stage of the water, which occurs annually in the winter, they may be grasped and moved at a still greater depth.

A progress shoreward of a foot or two in a year, would, in a few centuries, transport them many hundred feet. These processes now open to observation are, like those on a more extended scale, of the drift era, slow but irresistible, and capable, after long periods, of producing great results.

Lakes of Erosion.

Along the north shore of Point Keweenaw, there is a series of long narrow bays, the depth and contour of which are largely due to glacier excavation. Copper harbor, Agate harbor, Eagle harbor, and Cat harbor are of this class. The strata are alternately trap, sandstone, and conglomerate, the strike of the beds being nearly east and west. Their longest axis is parallel with the strike of the rocks, which dip northerly. Between the lake and the waters of the harbors is a low uplift of trap, with narrow breaks, which form the entrances to still water in the rear. The course of the glacier movement was here from northeast to southwest, somewhat oblique to the strike of the rocks.

Point Keweenaw is a high and narrow mountain range, the general course of which is northeast and southwest, except at its eastern extremity, where it curves to the east. It is at this part the harbors above named are situated. The high narrow crest of the centre line of Point Keweenaw, rising six hundred to eight hundred feet above the lake, modified somewhat the course of the movement. Lakes Schlatter, Fanny Hooe, and Upson, on the north side of the Point, are in the same elongated form east and west as the coast harbors. On the height of land are Lake Manganese, Musquito lake, and Portage lake, situated in breaks of the mountain range, where the mechanical effects are less prominent, but they show erosive action, and the change of direction due to gaps in the range.

On the island of Isle Royal the same strata occur, with the same northeasterly strike. Here there is a rapid succession of hard trap with softer sandstone and conglomerate beds, their dip being to the south. This island presents the most remarkable cases of erosion. Whether upon the coast or in the interior, there is scarcely a square mile that does not exhibit distinct glacier action. Here also the bearing of the striæ very nearly coincides with the strike of the rocks.

At the eastern extremity is a series of narrow ledges, which might be aptly compared with the fingers of a hand, and which are composed of trap; the spaces between represent numerous straits and harbors, with sandstone at the bottom. There are troughs of excavation which extend southwesterly the entire length of

the island, a distance of sixty miles. Siskowit harbor, Rock harbor, Washington harbor, and Tod harbor are exact imitations of those on Point Keweenaw. In the interior, between the ridges, at all elevations above the lake, to the summit of the island five hundred and six hundred feet, are long narrow lakes, the longest axis being, as usual, parallel with the outcrops of the rocks. These rocks are more denuded than upon Point Keweenaw, and are everywhere rounded, scoured, and striated. To the west and southwest, along the north shore of Lake Superior, the rocks have nearly the same strike, and dip towards the south and southeast, but were not as thoroughly exposed to the drift forces, owing to a mountain range on the north, ten to fifteen miles distant.

The northerly and northwesterly faces of the highlands received the first and greatest pressure. To the south of Point Keweenaw, in Marquette county, is repeated what had occurred on Isle Royal. The islands and rocky points, headlands and islets around Presque Isle bay, Riviere Des Morts, and the village of Marquette are thoroughly ground down to dome-shaped surfaces, with warped floors, troughs, grooves, furrows, and striæ, the general course of which is southwesterly.

Here the strike of the strata is nearly east and west with less difference in the beds as to hardness. On the coast north of Marquette there are outbreaks of sienite and granite, which did not resist the movements so well as the trap and iron beds. The quartz strata and the marble beds are less affected than the azoic slates, but are all highly polished, the exceedingly fine striæ etched thereon remaining almost as perfect as they were when the icy graver finished its work.

On the summit, there are the Teal and Matchigummi lakes, surrounded by the same evidences of ice action; but their form has not been as much changed by it as those on Isle Royal. To the northwest of Lake Superior, along the line of Pigeon river and Rainy lake river, this action is very conspicuous. Vermilion lake, which is in the Mesabi range, is surrounded by gneiss, granite, and slates, having a northeasterly and southwesterly trend.

Rainy lake has a geology very similar. Both of them present a labyrinth of islands, inlets, bays, straits, and harbors of the most interesting and complicated character. The rocks are not bold, but mostly divested of earth, and thoroughly abraded. On the softer portions, such as recent granite and talcose slates, the effects are visible only in the smooth dome-like moutonnes, without striæ; but on the quartzose portions the markings are yet distinct. But we must extend our ideas of glacier excavation to larger bodies of water. The basins of the North American lakes, constituting the valley of the St. Lawrence, have been modified by the same agent. By consulting the accompanying map, it will be seen that the direction of the movement was in general along their longest axes.

It is remarkable that most of them have the long axis nearly in the directions of the bearing of the rocks. In some cases, the strata which have least resisting power lie at the bottom of a lake; and more than this, the course of the arrows shows that the glacier moved along the outcrop of these beds, having the same general direction, thus combining all the circumstances favorable to erosive effect.

At the bottom of Lake Ontario are the rocks of the New York system, from the

Potsdam up to the Medina sandstone, embracing the Utica slate, Shawangunk grit, and Hudson river group; beds not calculated to resist denuding forces of any kind. Lake Champlain formed a lateral channel also on the line of strike.

Probably the series of interior lakes of Middle New York, with their axes north and south, will on examination show a local parallelism with the drift force. Passing to Lake Erie, there is less uniformity. The course of the striæ along the south shore varies from south to south 80° east.

Of their bearing on Lake Huron I have no information; but what I have seen on Lake Erie indicates a meeting of forces in this neighborhood. The strata at the bottom of this lake are such as to be easily reduced; but the lake is a shallow one, nowhere reaching 300 feet in depth. Most of it is less than 150 feet.

The upper silurian limestones form the shore at both ends, curving to the north into Canada. Above these rocks are the Hamilton and Marcellus slates, more properly shales, which are soft and clayey. These shales form the southern coast from Cattaraugus creek to Huron river, and outcrop beneath the water towards the Canada shore. If there had been a steady movement from northeast to southwest, along the edges of these strata, there should have resulted a deeper depression. The same shales extend through the greater part of Lake Huron, dipping to the west and southwest.

Indications are that the movement was here as on Lake Erie, across the strike of the beds, or, if not so, it was irregular. In the Straits of Mackinaw it was from east to west. There is in Central Michigan no high land to divert the glacier mass from its general southwesterly course; and the arm of Lake Huron, known as Saginaw bay, approaches very near to the central portion.

It is probable that this bay will be found to be one of the channels which it followed. The western outcrops of the same soft shales and sandstones lie beneath Lake Michigan. Around them are the same upper silurian limestone beds that are seen on the north shore of Lake Huron. The western coast of Lake Michigan is composed of these silurian strata, which have much more resistance than the shales. Along the western shore of this lake the glacial striæ have a very uniform direction, which varies little from southwest.

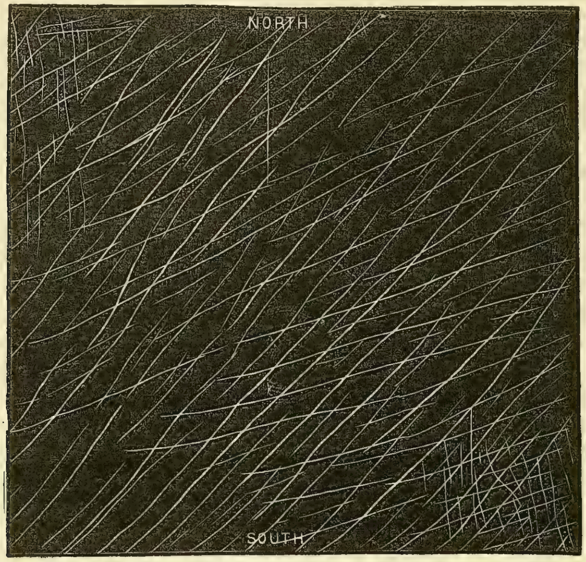
Along the north shore their bearing is more westerly. There was a deflection to the southward along the axes of Lake Michigan, Green bay, and Lake Winnebago, which brought the motion nearly into parallelism with the outcrop of the rocks.

The fac-simile of striæ at Sheboygan shows two sets of lines, one more to the east than the other. That curve corresponded very closely with the change of dip and bearing of the rocks. The lower peninsula of Michigan occupies the centre of a geological basin, the surface rocks of which are the coal series. The rocks of the upper peninsula of Canada, northern Ohio, Indiana, and Wisconsin dip beneath this coal series on all sides.

On the north shore of Huron and Michigan, the inclination is to the south. On the western shore of Michigan it is southeasterly, and at length eastwardly, having the slates of the Hamilton and Marcellus groups on the east and at the bottom of

the lake. The western half of Lake Superior occupies a synclinal basin in the Potsdam sandstone, and its long axis coincides with the glacier movement precisely.

Fig. 11.



FAC-SIMILE OF A SLAB OF NIAGARA LIME-ROCK, polished and striated by the drift forces; from beneath the red clay. Sheboygan Light-House, Wisconsin.

The tough trap rocks rise on both sides above the sandstone. As the continental glacier pursued its course to the southwest, it was divided and resisted by the trap ranges ploughing out for itself channels such as Keweenaw bay, Chefoimegon bay, and the larger bay at the west end of the lake, which terminates at Superior city.

CLEVELAND, OHIO. June, 1864.

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MAY, 1866.

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GEOLOGICAL RESEARCHES

IN

CHINA, MONGOLIA, AND JAPAN,

DURING THE YEARS 1862 TO 1865.

BY

RAPHAEL PUMPELLY.

[ACCEPTED FOR PUBLICATION, JANUARY, 1866.]

THIS memoir, having been approved by the National Academy of Sciences, has been accepted for publication by the Smithsonian Institution.

JOSEPH HENRY,
Secretary S. I.

COLLINS, PRINTER,
PHILADELPHIA.

PREFACE.

The material for the following pages was collected since 1860. Leaving the Eastern States in that year, and crossing the plains to Arizona, I remained there nearly a year in charge of silver mines. Being forced by the Indian troubles to abandon that territory, I entered Mexico, and after a midsummer journey over the deserts of the Pacific coast, between Sonora and California, reached the latter State.

Leaving California with one companion, Prof. William P. Blake, both of us engaged by the Japanese Government to explore the island of Yesso, we sailed for Japan *via* the Sandwich islands. The engagement with the Japanese Government lasted but little more than a year, when it was suddenly brought to an end by the fierce political troubles of that time. It was during hasty journeys of reconnoissance that the notes relating to Yesso were jotted down, and at a time when I hoped to be able to make a much more thorough study of the geology of Japan.

It was with true regret that I left the service of a government whose courtesy had made a lasting impression on my memory, and with whose struggles for progress as against exclusiveness I deeply sympathized.

Crossing to China, after a short visit to Nagasaki, I ascended the Yangtse Kiang into Central Hunan, and to the frontier of Sz'chuen, a great part of the journey being made in a small Chinese boat, and occupying four months of the spring and summer of 1863.

The autumn and winter of 1863 and spring of 1864 were spent in examining the Coal fields west of Peking, for the Chinese Government, and in journeys in Northern China and Southern Mongolia.

I spent the summer of 1864 at Nagasaki.

In the winter of 1864 and 1865, in company with Mr. T. Walsh, of Japan, and Mr. F. R. St. John, Secretary of the British Legation at Peking, I crossed into Siberia, and thence, alone, travelled overland to St. Petersburg and Paris.

Thus the journeys which furnished the data for the following pages were as follows:—

I. In 1862 over the ground indicated in the sketch map of southern Yesso, Pl. No. 8, and excursions in the neighborhood of Yokohama.

II. In 1863 excursions in the vicinity of Nagasaki; a journey up the Yangtse Kiang to the boundary between Hupeh and Sz'chuen, and into southern Hunan; and excursions from Peking into the mountains of northwestern Chihli.

III. In 1864 a journey in southern Mongolia, along the edge of the plateau to

near the great N. E. bend of the Hwang Ho, returning to Peking by a route south of the plateau and within the Great Wall; and finally, part of the journey homeward, from China across the plateau and the Gobi desert to Siberia.

With the exception of the itinerary in Yesso, which was made while in the service of the Japanese Government, and the description of the coal basin west of Peking, which was examined at the request of the Chinese Government, all the material was collected on journeys made at my expense.

Ignorance of the Chinese and Mongolian languages, the difficulty of making observations in western China, owing to the hostility of the people at the time, the intense cold of the winter journey across the plateau into Siberia, and the fact that the enterprise was a private one, will, it is hoped, serve as excuses for asking the indulgence of the reader in view of the incompleteness of the work.

I have attempted throughout to keep the generalizations separate from the record of observations and other data on which they rest.

I have followed, generally, the orthography of Dr. S. W. Williams for Chinese proper names, and that of Klaproth for Mongolian names, where these could be found on his great map of Central Asia, but in many instances they are written from the pronunciation of the Tartar guides. In giving Japanese and Aino names I have followed very closely the Japanese spelling.

For assistance in preparing the present work I am indebted to Dr. J. S. Newberry for undertaking the description of the fossil plants, and to Mr. Arthur Mead Edwards for the examination of infusorial earths, etc., under the microscope, and to Prof. G. J. Brush and Mr. James A. Macdonald for analyses of coals.

A considerable amount of valuable material consisting mainly of Paleozoic, Tertiary, and Post-tertiary shells, and of rocks, has not yet been worked up.

I would return thanks to Prof. J. D. Whitney both for many valuable hints, and for the use of his excellent library.

I am deeply indebted to Dr. W. Lockhart, Mr. C. Murray, and Dr. S. W. Williams, and Rev. Mr. Edkins, of Peking, for valuable assistance in making researches in Chinese geographical literature.

The diagrams in the text, and the plates, I. to VIII., at the end, are executed in copper relief engraving by Messrs. E. R. Jewett & Co. of Buffalo; plate IX. is cut in wood by Mr. C. Murry, of New York.

R. P.

New York, Aug. 1, 1866.

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GEOLOGICAL RESEARCHES

IN

CHINA, MONGOLIA, AND JAPAN.

CHAPTER I.

ON THE GENERAL OUTLINES OF EASTERN ASIA.

If we examine a Mercator Chart of Eastern Asia, we are instantly struck with the parallelism of many of its most important features. A straight line (*A*, *B*, Pl. VII) drawn in the longer axis of the Gulf of Pechele, trending nearly northeast (N. 47° E.), if prolonged in both directions, will be found to coincide with the entire middle course of the Yangtse, between Sz'chuen and Yunnan, with the longer axis of the great delta-plain between the highlands of Shantung and western Chihli, with the mouth and lower course of the Liau river, with the valley of the lower Amur, and finally crossing the Sea of Ochotsk, it is parallel to, and nearly coincides with, the direction of the Gulf of Penjinsk.

Using this line as a standard of reference, we find that the long straight western shores of the two greatest indentations, the Sea of Ochotsk and the Bay of Bengal, are nearly in a line with each other and parallel to our standard. The same may be said of a line connecting the islands of Formosa, Kiusiu, Nippon and the Kuriles. The trend of the southeastern coast of China, the upper course of the Yellow river, the Lake Baikal, and the courses of many of the principal rivers of Eastern Siberia; that of Kamtschatka and the coast of Manchuria are all separate instances confirming this rule.

We are naturally led to look for the cause of this in a similar uniformity in the trend of the mountain ranges, and, indeed, although the directions of these are difficult of determination, I hope to be able to show that such a parallelism really exists. The long, submerged chain represented by the Kurile and Japanese islands is an unmistakable instance, while, in the northern part of the continent, the Stanovoi and Yablonoi ranges, and all the ridges of Trans-Baikal, are examples of mountains nearly or quite parallel to our standard, and inclosing extensive longitudinal valleys. The same may be said of the Byrranga mountains, and of almost all the ridges east of the Lena river. Indeed, while the trends of nearly all the mountains of Northeastern Asia lie between N. N. E. and E. N. E., the majority of them approach very nearly the N. E. S. W. direction.

Having seen that this regularity exists in the ranges of the better explored parts

of Eastern Asia, let us look for it in China also, where we have to rely on a more limited number of data, partly geological and partly topographical in their character.

Where the Yangtse river crosses the Sz'chuen-Hupeh frontier, it cuts through a broad mountain range whose principal axis crosses the river in long. 111° 15′, near Ichang (fu). Here the axial granite rises 600 to 1000 feet above the river, and is flanked on both sides by an immense thickness of limestone and coal-bearing rocks, whose strata have here a mean trend to N. E. If, through this point, we draw a line (*C*, *D*, Pl. VII) having a similar trend, its prolongation will indicate the watershed between the Hwai river and the Han river, the watershed of Shantung, and following the line of islands that stretch across the entrance to the Gulf of Pechele, it will coincide with the range of mountains, which, beginning with the promontory of Liautung, divides the waters first of the Liau river and Yaluh river, and afterwards, of the Sungari river and Usuri river. If we prolong the line from the Yangtse to the S. W., it will nearly coincide with the mountains that part the rivers of Kweichau from those of Hunan.

All these ridges I take to be members of a continuous line of elevation, extending from Southern China to the Amur river, and which, from its influence on the character of the country, may be called the central anticlinal axis of China.

A line drawn from near Canton and passing through the Chusan archipelago, will represent the mean trend of the coast range, and, if prolonged to the N. E., it will cut the Corean peninsula near its southern end, in what appears to be its most mountainous point.[1] In the other direction, the island of Hainan, from its N. E. S. W. trend and lofty mountains, would seem to be a member of the same range.

In Northwestern China, a great range crosses the Yellow river, in its course between Shansi and Shensi, and trending N. E. by E., connects the mountain knot of Northwestern Sz'chuen with that of the Ourang daban north of the Tushïkau gate of the Great Wall. Nearly parallel to this is another range which, beginning west of Singan (fu), crosses the Yellow river, forming the Lungmun gorge, and traversing, obliquely, the centre of Shansi, gradually approaches the other range in northern Chihli.

These are the three principal axes, and they seem to be made up of parallel anticlinal ridges. Minor parallel axes seem to occupy the country between these larger ranges.

If we examine the maps of the provinces that border on the eastern edge of the Tibetan highland, we find a system of ranges, which, branching off from the Kwenlun and following, at first, a southeasterly course, gradually merge into a N. S. trend. The easternmost of these, occupying western Sz'chuen, divide the principal northern tributaries of the Yangtse. Those farther west form the narrow watersheds between the upper courses of the Yangtse, the Cambodia and the Salween, and, in their southern prolongation, they form the Malayan peninsula and probably that occupied by Annam and Siam. The N. S. trend seems to be confined exclusively to the extreme west of China.

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[1] According to the great map of Kanghi this peninsula seems to have its principal mountains in the south, forming a N. E. S. W. ridge.

On the other hand the E. W. system of trends, which is so important in Central Asia, exercises an influence which is apparent much farther eastward.[1]

A range of mountains, said to have several snow-covered peaks, originating in Southern Kansuh, runs due east, separating the waters that enter the Yellow river through the Wei and the Loh, from those that flow to the Yangtse through the Kialing and the Han, and finally disappears in western Honan. Another range, with a mean E. by S. trend, is given by Klaproth as forming the boundary between Sz'chuen on the south and Shensi and Kansuh on the north.

It is not improbable, that the country included between these two ranges in Shensi and Kansuh, is an elevated table-land. The courses of the Han and Kialing rivers and the communication between their waters, as indicated by Chinese authorities, seem to favor this idea.

In the south, the Nanling mountains, a range said to have peaks that reach above the snow-line, rise in Yunnan, and, branching, form, in the northern member, the boundary between Kwangsi and Kweichau, while the southern member trends off into Kwangsi. The influence of the northern branch of the Nanling, is apparent as far as Fuhkien, in the probably comparatively low watershed north of Kwangtung. The higher portion of this range seems to be along the southern boundary of Kweichau, where it has lofty peaks and fertile elevated table-lands,[2] which, from difficulty of access, have been for ages the home of the aboriginal Miautsz, a race unconquered by the surrounding civilization. The two passes that cross this range in Hunan and Kiangsi, where it is called the Meiling, cannot be very high, as the portage between the head of boat navigation on the two flanks is only a few miles. According to Biot,[3] the members of Lord Amherst's embassy give the height of the Kiangsi pass as 3000 feet. The great map of Kanghi gives an uninterrupted water communication between the headwaters of the Siang river of Hunan and those of a tributary of the Si river, that flows through the city of Kweilin.

I have here attempted to trace only those ridges which seem to be the most important, as exhibiting the general configuration of China. To the E. W. ranges is due the fact, that the mean courses of the great rivers of the empire lie east and west. But the total length of each river is made up of N. E. reaches, where it flows through broad and fertile longitudinal valleys, and of southeasterly or southerly reaches in which it traverses, by deep and narrow gorges, the N. E. S. W. ridges.

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[1] All that is known of these two systems, the N. S. and the E. W. is derived from the Jesuit maps and from Chinese writers.

[2] Chinese Repository, I. 40.

[3] Recherches sur la hauteur, etc., Journ. Asiat., 1840.

CHAPTER II.

GEOLOGICAL OBSERVATIONS IN THE BASIN OF THE YANGTSE KIANG.

A GLANCE at the section (Pl. 1) across Central China will show that the Devonian limestone and Chinese Coal measures seem to predominate, at least at the surface, over all else. There is only one point in the whole length of the section, where rocks older than the great limestone deposit rise to the surface, so that if the former exist, they are buried deep below the level of the sea. I shall give, in a subsequent chapter, reasons for believing that, at least in the valley of the Yangtse, there are also no representatives of the Mesozoic formations of later date than the Chinese Coal measures, and few, if any, of the Cenozoic.

Where the Yangtse breaks through the ridges of the central anticlinal axis of elevation, in Eastern Sz'chuen and Western Hupeh, a section, nearly eighty miles long, is exposed in the succession of deep gorges through which the river passes this barrier. Here the Devonian limestone is seen to rest almost immediately on the granite, a comparatively small development of metamorphic schists intervening.

This seems to be the only point between Western Sz'chuen and the Pacific, where the Yangtse has exposed these lower rocks, and even here they occur during only about eight miles of the river's course, and with a maximum height of only a few hundred feet above the river. To their occurrence are due the rapids that render the navigation of this part of the "Great River" so dangerous.

The granite immediately above the first rapids consists of a triclinic feldspar and orthoclase, the former predominating, a brilliant black mica and quartz with small crystals of sphene scattered through the mass. Above Shantowpien the granite becomes very fine-grained, and still further up the river it is succeeded by syenitic granite, composed of white triclinic feldspar, quartz, large laminæ of brown mica, and crystals of hornblende, with minute octahedrons of magnetic iron.

On its eastern and western declivities the granite supports the metamorphic strata. Those to the eastward, which could not be closely examined, seemed to be gneiss trending E. W. and dipping about 30° to S. West of the granite the strata consist, where examined, of hornblendic schist and chloritic schist, the former often containing lenticular masses and cross veins of quartz, feldspar, and chlorite. Rolled fragments of diorite, probably of metamorphic origin, indicate the presence of this usual companion of these rocks. Near their contact with the granite these strata trend N. N. E., dipping about 85° to E. S. E., while further up the river their trend changes to E. N. E., and the dip to N. N. W.

Flanking this granite core on both sides and covering it, is the great Devonian limestone floor of the Chinese Coal measures. On the eastern flank of the granitic axis the limestone strata trend, almost uniformly, N. E. S. W., varying in dip from 25° to 8° towards the S. E. as we recede from the granite. On the western flank the strike is less regular, changing from nearly N. S., at the contact with the metamorphic schists, to N. E. S. W. in the upper part of the limestone. In the immediate neighborhood of the river, over an area of forty or fifty square miles, the limestone has disappeared, but in the distance, on both sides of the Yangtse, its yellow cliffs are seen towering to a height of more than 2,000 feet above the water.

I know of no limestone deposit that can rival this in thickness. Taking the length of the cross section from its contact with the younger conglomerates, near Ichang, to where it rests on the metamorphic schists, to be seven and one-half geographic miles, and the mean dip at 15°, viz., 10° for the eastern half and 20° for the western, we obtain the enormous thickness of 11,600 feet, more than two statute miles. I observed no faults in this gorge, and the great thickness observed in this same limestone in Northern China, leads me to think that the above estimate cannot be far from the truth.

West of this ridge of limestone is another of about the same size, the intervening space being occupied by the Coal measures.

Here, within a distance of eighty miles, are the principal rapids, while the river traverses the limestone through a series of five gorges unsurpassed in the grandeur of their scenery. The Yangtse, which, a few miles below the mouth of the Ichang gorge, has a width of 960 yards, is in this narrowed to 250, and in the Fungsiang gorge to 150 yards.[1] In these narrow passages, whose walls are from 900 to 1200 feet high, cliffs of bare rock, often vertical or overhanging, alternate with steep declivities clothed in green from the water to the summit, and with deep, inaccessible dells filled with the rich growth of a semi-tropical vegetation. Streams flowing from the mouths of caverns high above the river, cool the air in their descent, while the huge clusters of stalactite which they have formed—the work of ages—show well the chemical power of the smallest drop, side by side with the mechanical force of the rolling river. Through these gloomy chasms the skilful boatmen drag the heavy junks, now "tracking" them from paths and steps hewn in the solid rock, now pulling them by rusty and time-worn chains clamped along the vertical walls.

The depth of the water must be very great,[2] and the difference between high and low water is said to be as much as eighty feet in the Ichang gorge.

The limestone is generally of a bluish-gray color and compact texture, though subordinate to this variety, layers occur having every shade of color and grain. A gray, compact variety, with frequent large crystals of calcite is not uncommon; and a very compact, almost black kind is quarried in the Ichang gorge. Indeed gray, pink, red, black, and blue varieties of this same limestone, with compact, porphyritic and crystalline textures, furnish in almost every province of China

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[1] Blackiston. Five months on the Upper Yangtse.

[2] Blackiston's party found no bottom with eighteen fathoms.

useful and choice marbles. Every degree of thickness occurs in the layers from laminæ only one-quarter inch thick to beds of many feet.

Nodules and thin layers of black chert occur throughout the limestone, but in the lower half they are remarkably frequent, becoming more common as we approach the oldest beds, in which, indeed, the calcareous rock is often entirely excluded by massive layers of quartzite. At the eastern entrance to the Lucan gorge, where the limestone rests on the older rocks, the lowest beds of the former, containing lenticular masses and thin layers of chert, are soon succeeded by a bed 40 to 50 feet thick, of massive quartzite.

Wherever I have had occasion to examine this limestone in place, it has invariably appeared to be entirely without fossils, but this has been only in the main ridges, where metamorphic action has probably played a more important part than in the minor ridges that rise between these lines of greater elevation, and it seems to me that there can be little doubt that the fossil Brochiopoda that occur in many provinces belong to this formation.

Just before entering the eastern mouth of the Lucan gorge, a bed of fine-grained, micaceous, gray sandstone is observable, intervening between the metamorphic schists and the limestone. The trend of this intervening bed is N. N. W. and the dip 25° to 30° to W. S. W., the metamorphic schists striking to E. N. E. and dipping to N. N. W., while the trend of the overlying limestone strata, at the nearest point observed, was about N. by W. and the inclination about 30° to W. by S.

At the western end of the Mitan gorge we enter the coal field of Kwei. Here the limestone disappears under strata, apparently conformable with it, of a fine-grained micaceous sandstone, which, below Kwei, is succeeded by a fine-grained, gray, calcareous sandstone. The trend of the beds which, near the gorge, was N. N. E. with a dip of about 40° to W. N. W., changes here to N. with a dip to E., and further up, opposite Kwei, it is N. by W. with an inclination of 70° to E. by N. Here is the beginning of a series of those angular plications so common to Coal measures in all countries. Small beds of limestone and red argillite alternate with the sandstones until, about two miles above Kwei, the first coal seams crop out, and with the appearance of these, the trend changes to N. W. by W., more than 90° from its normal direction of N. E. S. W.

The seams of coal are of an inferior friable anthracite. Those I visited above Kwei were highly inclined between sandstone walls, and contained, according to the Chinamen, only six to eight inches of fuel. Capt. Blackiston, who took specimens of these rocks and noticed, with much accuracy, the general features of this region, remarks that the rocks of the coal regions of Sz'chuen, wherever he saw them, presented the same appearance as those of the Kwei field.[1] It would seem probable that in Sz'chuen, which seems to be occupied by an immense coal basin, the Coal measures exist with a much greater thickness than in the Kwei field, where only the lower members seem to have been preserved. Deposits of iron ore occur in intimate connection with coal and limestone in Sz'chuen,[2] and, as we shall

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[1] Five Months on the Upper Yangtse. [2] Ibid.

see later, it is probable that the extensive salt deposits of that province are members of the same formation.

Near the city of Ichang, at the eastern mouth of the gorge, the limestone strata, trending here N. E. and dipping about 8° to S. E., are covered by apparently conformable beds of fine-grained, gray sandstone, which, toward the top, soon merges into a coarse conglomerate. The change is very marked, the upper portion of the sandstone containing rounded fragments of chert near the contact, and the lower part of the conglomerate having lenticular deposits of the sandstone. This transition appears to mark some important change that took place during the forming of these deposits, and the fact that, in transverse section, they border the river for twelve miles and have a great thickness, would seem to indicate that this change was not confined to the immediate neighborhood.

This conglomerate is followed by a red sandstone, which above Itu dips easterly, and below that place westerly. From here eastward the country on both sides of the river is flat, the rocks being covered for the most part by alluvial deposits; but in the neighborhood of Yangchi limestone crops out in different places, with a very irregular strike between N. and W., and a corresponding dip to between N. and E. From this point to Hankau, the country, if we except a few isolated hills, is one almost unbroken plain, the ancient bed of the Tungting lake, in which the older rocks are covered by the lake deposits.

At the town of Shishan (Hien) an isolated hill rises from the plain, its almost vertical strata trending about N. 65° E., and consisting of sandstone, arenaceous shale resembling a similar rock of the Kwei coal field, and a shaly quartzose conglomerate. The outcroppings of the older rocks that appear, at intervals, between the outlet of the Tungting lake and Hankau are sandstones and argillites, which, from their general character and the fact that in one place their trend is toward a locality a few miles distant where coal is worked, would seem to belong to the Coal measures. The hills immediately above Hankau are of clay slates and argillaceous sandstone, and through the cities of Wuchang and Hanyang, stretches a ridge of sandstone altered to an almost compact quartzite.

The journey from Hankau to the sea was made in a steamer, stopping only at Kiukiang and Chinkiang, making the knowledge concerning this part of the river very imperfect. The only sources of information were constant observations, through a good glass, of the frequent natural sections made by the river, and the scanty remarks of a few travellers connected with Lord Amherst's embassy.

Below Sankiangkau beds of sandstone and conglomerate, trending S. W. and dipping 40°—45° to S. E., are exposed, and a few miles further down the river the city of Hwangchau fu is built on a low ridge of ferruginous sandstone, of which the raised beds strike due N., dipping about 30° W. About twenty miles S. E. from this city, hills of limestone, 800 to 900 feet high, form the southern bank of the river, the irregular trend of their strata varying from W. to S. W., and the dip, of about 40°, from S. to S. E. Twenty-five miles below this point the river breaks through another ridge of limestone, the strata of which have a strike to S. E. by S. and incline about 40° to S. W. by W.

The rocks on the outlet to the Poyang lake have all the appearance of limestone,

and this is the case with all the exposed sections from the outlet to the Siauku shan or Little Orphan rock. Below Tungliu coarse red sandstone is exposed, its upturned edges, which are here capped with the younger terrace deposits, trending to N. E. with a dip of 15° to N. W. At Nanking there are extensive quarries of limestone, while directly opposite the city, on the left bank of the Yangtse, strata of red sandstone trend W. S. W., dipping about 40° to E. S. E. Coal mines are worked in the immediate neighborhood of this city, especially on its eastern side. Soon after leaving the hills of Nanking the river enters the great delta plain through which it winds to the sea.

In a *résumé* I shall try, by means of a combination of the data given above, with information derived chiefly from native sources, to throw more light on the structure of this region.

TERRACES OF THE YANGTSE VALLEY.

At frequently recurring points along both the Upper and Lower Yangtse, we meet with deposits of gravel and clay, forming bluffs at the water's edge, or fringing the hills that form the walls of the valley. They are generally stratified in horizontal beds. Differing in height and in the character of their ingredients, there seems also to be a diversity of age. The extensive plain, once occupied by the Tungting lake, before it was reduced to its present size, is fringed by these terraces; for they recur constantly from Hankau to Yochau on the right bank of the river, and from this city along the eastern border of the lake, and form a belt which extends many miles to the south, and occupies nearly all the space along the southern edge of the lake, between the Siang and Yuen rivers. Again, where the river enters the lake plain, the tongue of land included by the river bend between Pahyang and Tung'sz, consists of the same deposit.

At the last named locality the deposit is made up of rounded pebbles of quartz and limestone, cemented with a stiff clay, and this is its general character at the junction of the Siang river with the lake and along the eastern shore. But the most general form of occurrence is that of a stiff blue clay, with irregular white spots. Near Tung'sz the terraces appear to be from seventy to ninety feet high, but below the outlet of the lake they vary from thirty to sixty feet. Blackiston mentions similar terraces as occurring at various points along the Yangtse in Sz'chuen.

The village of Tsingtan, at the eastern end of the Mitan gorge in Western Hupeh, is built on a terrace of conglomerate-breccia formed of fragments of limestone, chert, gneiss, and other metamorphic rocks, in form of rubble and rounded and angular fragments of all sizes, the whole firmly cemented by a calcareous tufa. This formation originally filled the valley from side to side, and its bluffs rise forty to fifty feet above high-water mark. In the rapid current that must always have scoured these narrow portions of the Yangtse valley, nothing but the coarsest material could resist the onward movement; and when an increase in the velocity of the stream took place, only those portions of the deposits were preserved which

were near enough to the limestone to be cemented into a hard mass by the waters flowing from it.

The bed of the Yangtse must have been cut to about its present depth, when a diminution of its average fall took place, permitting the formation of these terrace deposits. Subsequently another change, by increasing the fall, caused the river to scour out, again, the greater part of the valley. As with the river so with the Tungting lake; this large sheet of water, which then occupied all the plain of Hupeh and Hunan, must have been filled up with the terrace deposit, the remains of which now form its shores. With the returning increase of fall, the lake was scoured out by the rivers Yangtse, Han, Siang, and Yuen. Since this erosion, it would seem probable that the velocity of the current has slightly diminished, as the material brought down by these rivers has converted nearly nine-tenths of the former lake into dry land. A large part of this lake-plain is said, by ancient Chinese writers, to have been an immense marsh where it is now cultivated land.

We have, at present, no observations to show whether the oscillations of Central China, which are thus recorded in the Yangtse Valley, were contemporaneous with the raising of the western edge of the delta-plain; but whether they were or not, the cause which was exerted across the whole breadth of China, must be looked for in a vertical movement, either in the Tibetan highland or along the eastern coast.

A remarkable instance of the formation of a deposit of fine material, in the swiftest part of the river, is observable in the first rapids, just above the Ichang gorge. Granite rocks rising to the surface, near the shore, form an obstruction to the current, which is here from fifteen to eighteen miles an hour, causing eddies in their lee, in which a constant precipitation of sand takes place. Banks of quicksands are thus formed, their tops almost even with the surface of the river. Their sides, too steep to remain at rest, are constantly being washed away, and as constantly replaced by the freshly precipitated material. At low water these banks line the shores, and, during the high water season of 1863, I noticed one more than half a mile long, and twenty-five or thirty feet above the river; the result of some previous very high freshet.

CHAPTER III.

OBSERVATIONS IN THE PROVINCE OF CHIHLI.

ALONG the western boundary of the province of Chihli, the great delta-plain is bounded by the outliers of the northwestern belt of N. E. S. W. ridges. The foundation on which rest the limestone and volcanic rocks of Northern Chihli, Shansi, and Shensi, consists of granite and the metamorphic schists; and where this foundation forms the northwestern limit of the delta-plain, it forms also the southeastern edge of the skeleton of the great table-land of Central Asia.

We have seen that, in Central China, the granitic and metamorphic rocks that support the limestone and Coal measures, rise to the level of the river, in, to say the least, only rare instances, and then as the axial cores of ridges; the great thickness of the overlying rocks making it highly probable that, from western Sz'chuen to the Pacific, this foundation lies far below the level of the sea. But if we cross the mountains from the delta-plain to the highlands of Mongolia, we find that the surface of the granitic substructure lies everywhere above the sea, and probably nowhere at a less height than 1000 feet. Were the limestone and younger rocks removed, the country would present the appearance of a table-land ribbed with high N. E. S. W. ridges, and very similar to southern Mongolia if we suppose that divested of its lava beds.

Along the edge of the plain, the limestone floor of the Coal measures rises abruptly from under the delta-deposit, and forms, so to speak, the eastern facing of these mountains. At the entrance to the Nankau pass, the strata trend N. 60° E. and dip about 40° to S. E. Five or six miles farther west, it is followed by granite, and between these points, strike and dip are very irregular. From the pass, the limestone stretches away to N. E. toward Jehol, and to S. W., facing the plain, toward Shansi.

While the Coal measures probably remain intact under the delta-plain, from the mountains of Shantung to those of Chihli, they exist in these latter only in scattered basins, where they have been partially preserved, by folds of the limestone, from denudation. The most important instances of this kind facing the plain, are the basins of Wangping (hien) and Fangshan (hien) west of Peking, and of Pingting (chau) in Shansi.

The basins of Waugping (hien) and Fangshan (hien) lie in the mountains west of Peking, where, rising from under the plain, they occupy synclinal folds of the limestone, and are probably only two arms of a larger basin concealed under the younger deposits to the eastward. The Wangping basin extends due west more than thirty miles, with a breadth of about twelve miles. Along a great part of its

northern edge, a bed of porphyry conglomerate, of great thickness, intervenes between the limestone and the coal rocks, while the western portion of the basin is much broken up by porphyries, and the centre is crossed by a high ridge apparently of quartzose conglomerate and sandstones.

Coal seams, varying in thickness and quality, occur in many parts of these basins, and are worked in the more accessible localities, as, for instance, at Muntakau, Maanshan, the hill of Piyünsz, Lingchi on the Wangping creek and at Chaitang in the west.

In the following necessarily incomplete table, I have attempted to show the structure of those parts of these basins that came under my observation:—

6	Coal or anthracite alternating with beds of argillaceous shales, sandstones, gray quartzose conglomerate-breccias and compact red and green argillites.	Hsingshun and Tatsau.	Chaitang district.
5	Alternating beds of coal, argillaceous shales, and sandstones.		
	Coal (Futau seam).		
	Black under-clay.		
	Micaceous quartzose sandstone.		
	Quartzose conglomerate.		
	Yellow argillaceous shale with impressions of plants.		
	Outcroppings concealed for several hundred feet by terrace loam.		
	Compact green argillite.		
	Coarse gray sandstone and conglomerate.		
	Compact argillite, mottled green and red.		
	Coarse gray sandstone.		
	Friable and argillaceous gray sandstone.		
	Red calcareous clay slate.		
	Greenish sandstone (with specks of chlorite).		
	Red calcareous clay slate.		
	Gray sandstone.		
	Red calcareous clay slate		
	Gray sandstone.		
	Green quartzose conglomerate.	Muntakau.	
4	Anagenite (quartz, feldspar, and mica sandstone).		
	Argillaceous shales and compact sandstones alternating with seams of anthracite.		
3	Ferruginous sandstone altered to quartzite.	Maanshan.	
	Quartzose conglomerate.		
	Anthracite.		
	Micaceous, and black argillaceous shales.		
	Calcareo-argillaceous shale.		
3	Anthracite.	Fangshan at Yingwo mine.	
	Micaceous, and black argillaceous shale.		
	Calcareo-argillaceous shale.		
3	Clay-slates (green, black and red).	Niuchauling.	
	Greenish sandstone passing into greenish quartzose conglomerate.		
	Argillaceous shale.		
2	Conglomerate of porphyry, limestone and quartz.	Hun Ho and Chaitang.	
	Porphyry conglomerate.		
1	Upper limestone.	Upper Yangtse and Province of Chihli.	
	Black clay slate.		
	Lower limestone (cherty).		

The porphyry conglomerates, No. 2, which, in places along the northern edge of the basin, have a thickness of not less than 2000 feet, are wanting in the eastern part. The parts of the series marked No. 3, form the oldest beds, and they rest immediately on the limestone in their respective localities. Between Nos. 3 and 4 the character and extent of the intervening beds were not observed. The connection between Nos. 4 and 5 is made on lithological grounds, the same green sandstone and green quartzose conglomerate occurring above the coal seams of Muntakau, and low down in the series at Chaitang.

Limestone.—Here, as on the Yangtse, a great development of limestone forms the floor of the Coal measures. Although no good opportunity occurred, in this region, for estimating its thickness, this is undoubtedly several thousand feet. It is generally divided into two nearly equal parts by a bed of clay slates; though independently of this, the upper and lower strata are characterized, the latter by an abundance of chert, and the former by comparative freedom from that mineral.

The limestone is generally compact and blue, but in places it is white and saccharoid; and black, pink, and dark red varieties occur. The chert is black, and is abundant in the lower half, occurring in nodules, and in layers varying in thickness from less than one line to over forty feet, beds of this size generally forming the bottom of the limestone. In the basin of Siuenhwa (fu), near the Great Wall, the limestone is highly siliceous, but almost always retains a white appearance.

This formation furnishes, here, as in almost every province of the empire, besides lime, the marble so much used in Chinese ornamental architecture, for bridges, tombstones, gateways, and the lions that guard the portals of all official buildings. The white saccharoid variety is very beautiful, but disintegrates so rapidly that, even in the dry climate of Peking, inscriptions on exposed monuments two hundred years old are barely legible.[1] The black variety, which is very compact, breaking with a conchoidal fracture, retains a perfectly fresh surface after centuries of exposure.

A quarry at the Maanshan has supplied lime for the capital during many centuries; the continued excavation having widened and deepened the valley, removing small hills and leaving, over an area of perhaps one square mile, a deposit that might well perplex an observer, were the cause not still at work. Almost every point in this area seems to have been the site of a lime-kiln, which has left its cone of concentric layers, consisting of half burnt limestone, chert, fragments of coal and ashes. As new kilns were built over and between old ones, the result is a bed, the ingredients of which have become cemented to a hard concrete, by the refuse lime. In this deposit, the stream of the valley has cut its channel, in places, forty to fifty feet deep, with vertical walls, without reaching the limestone bottom.

Caves are abundant in this limestone, and many of them are said to be of great extent. One which I visited, near Fangshan (hien), consists of a series of large

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[1] There is a white variety, used in monuments near Peking, in which inscriptions of the Kin dynasty are perfectly fresh, as, for instance, that used in the grand marble arch of Kiyungkwan in the Nankau pass.

chambers extending nearly in a straight line. The first two of these only were visible, the entrance to the third having been closed by an imperial order, owing to a party of visitors having lost their way and perished.

These chambers are connected by passages, so small that they can be entered only by creeping on hands and knees. Their longest axis is at right angles to the strike of the strata, and forms a considerable angle with the dip. The floor is covered with stalagmite, which, in the centre of one chamber, seems to be at least forty feet thick, and is connected with the roof by immense columns of stalactite. Like many large caverns in China, this one is sacred to Buddha, of which deity there is a well executed high-relief sculptured in the wall of the entrance; and the small passages have been worn and polished by the knees of pilgrims during centuries.

I looked in vain at the face of the rock at the entrance, for some signs of a crack corresponding to the plane of these chambers.

Some of the deep and narrow ravines of the surrounding hills, seem to have been formed by the caving in of similar caverns.

In parts of the empire, these caves abound in fossil bones, which are excavated and used in medicine, under the name of "dragon's bones," "dragon's claws," etc.

This limestone, forming, as it does, the floor of the Coal measures, appears, surrounding the different basins of these, in highly inclined beds, forming as it were a narrow frame, or, having a gentler dip, it occupies a broader space.

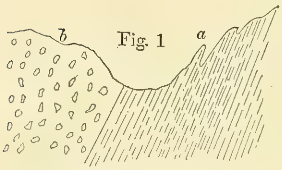
Porphyry Conglomerate.—In the mountains that border the Wangping basin on the north and west, there are extensive masses and dykes of porphyry, which have raised and cut through the limestone in all directions. From the detritus of this intrusive rock, the beds of the lower Coal measures at Chaitang, which are equivalent to those marked No. 3 in the table, seem to have been formed. The reason for supposing this, is, that as we approach the northern edge of the Chaitang basin, we find the porphyry conglomerate underlying, in the form of a flat boss, the beds forming the lower half of No. 5 which are eminently characterized by two peculiar rocks, that marked as "compact green argillite" and the still lower ones, "green quartzose conglomerate." Further on we find, that the porphyry conglomerate contains interstratified beds of sandstone. The fragments that form this extensive member of the Chaitang series, are, for the most part, derived from the masses of porphyry nearest at hand. Thus near Chingtai they are chiefly green felsitic porphyry, similar to that forming dykes in the limestone at Hiamaling, a few miles distant, while, along the Hun river, red and green varieties predominate, intrusive masses of both kinds occurring in the neighborhood.

Fragments of limestone and quartz are frequent in the porphyry conglomerate, and would seem to characterize its upper portion. Thus I have indicated in the table two distinct varieties, though perhaps on insufficient grounds.

This conglomerate furnishes an important page in the history of the Coal measures in this region. It shows us that there had been an elevation of the limestone, perhaps caused or accompanied by the intrusion of the porphyries, before the overlying rocks were deposited. The presence of fragments of limestone, quartz,

and porphyry, shows that these older rocks had been subjected to an extensive denudation.

In the narrow gorge, through which the creek finds its way from the Chaitang valley to the Hun river, the contact between the limestone and porphyry conglomerate is visible (Fig. 1). The limestone strata are cut through at a right angle, and are seen to dip about 80° to the S.



a. Upper limestone.
b. Lower porphyry conglomerate.

I did not obtain an observation of the dip of the conglomerate in this section to know whether it conforms to that of the limestone.

The coal district of Chaitang forms an area of low hills, and is limited on the north by the porphyry conglomerates, whose high and rugged hills are overtopped in the background by the yellow cliffs of the limestone. To the south rises a high ridge consisting, apparently, of the rocks of the Coal measures and dykes of porphyry, and separating the coal district of Chaitang from that of the Wangping creek. To the west is a high and hilly country mainly of porphyry.

About four miles W. N. W. of Chaitang, in the midst of this porphyry, lies the small coal district of Chingshui, and about five miles S. W. are the anthracite mines of the Tatsau district.

The valley of Chaitang has been occupied by a lake, the alluvial deposits of which now form terraces and cap hills over one hundred feet high. The trend of the tilted strata in the centre of the district is very uniformly N. W., and the dip is to N. E. and to S. W., forming both synclinal and anticlinal ridges. But as we approach the western end the trend becomes irregular, though the dip is toward the porphyry. Indeed, the edge of these mountains of porphyry, seems to mark the line of a great fault, perhaps combined with an immense overflow of that rock.

The following description of the more important coals is extracted from my Report to the Chinese Government, which is published in the "United States Diplomatic Correspondence, 1864, Part III."

For more perfect analyses of some of these and other coals by Mr. J. A. Macdonald, the reader is referred to Appendix No. 2.

Principal Mines.—The Futau mine, which lies about five li (less than two miles) S. S. E. of Chaitang, and from one hundred and fifty to two hundred feet above the level of the creek at that town, is remarkable as producing a "steam coal" that is equal if not superior to the best Welsh variety.

The seam, in which several openings have been made, is irregular in thickness, this varying from six to twelve feet, though in the mean averaging, probably, not less than seven feet. Near the roof the coal has a tendency to crumble, near the floor it is slaty; all the rest of the seam furnishes large blocks of firm and excellent fuel.

The coal has a brilliant lustre, is made up of well-defined layers, and has a tendency to a cubical fracture. It ignites quickly, burning with a long flame and little smoke.

Opening slightly, it burns without caking and without falling to pieces, and leaving a very little gray ash.

I found by dry assay, using the exceedingly imperfect means at my command in Peking, the following results:[1]—

Sp. gr.	1.31
Parts of lead reduced from oxide by one part of coal	31.50
Corresponding value in units of heat	7245.00[2]
Percentage of ash	4.00

There are several seams parallel to this one both above and below it, one of which is six or seven feet thick, and only thirty feet above it. The dip of the beds is about 45°.

So defective is the Chinese system of mining, that the proprietor of this mine could not undertake to furnish from it more than eight hundred and fifty tons yearly. The selling price, at the mouth of the mine, is $2 00 per ton of 2,000 pounds.

In the Fushun mine, apparently on the same seam, the coal reaches a thickness of thirty-five feet, though it averages much less.

Hsingshun Mine.—This is on one of a series of seams, that crop out in a valley about five li N. W. of Chaitang, and which I take to be younger than that of the Futau. The horizon of these seams is well characterized, in the Chaitang district, by the occurrence among them of beds of a peculiar quartzose conglomerate breccia, called by the natives horsetooth stone (from the appearance of pieces of chert it contains). This rock forms the floor of the seam in which lies the Hsingshun mine, while the roof is sandstone, and between these the seam dips at first 50°, changing gradually to 90°. Within a limited space the thickness of the coal varies from three to eight feet.

The coal is without lustre, and has an irregular flaky structure. It ignites quickly, burning with a long flame, cakes readily and leaves a red ash.

Sp. gr.	1.28
Parts of lead reduced by one part of coal	31.40
Units of heat	7222.00
Percentage of ash	3.00

The miners burn it in small heaps to a very light and porous coke.

Tatsau Mine.—About five miles S. W. of Chaitang is the Tatsau, or "great seam" of anthracite. It consists of two seams separated by about eight feet of sandstone, the upper one being from twenty-three to thirty-five feet thick, and the lower from seven to eighteen feet. The roof is formed by the same peculiar conglomerate breccia that characterizes the Hsingshun beds, the floor being sandstone, and dipping about 45° to N. W.

About six-tenths of the produce is anthracite of a superior quality, coming out in

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[1] See Appendix No. 2.

[2] Without the correction of $+\frac{1}{8}$.

large, firm pieces formed of well-defined layers, with conchoidal fracture and brilliant metallic lustre.[1]

Sp. gr.	1.55
Parts of lead reduced by one part of coal	33.40
Units of heat	7682.00
Percentage of ash (gray)	4.00

Eight men produce about four tons daily, and the selling price at the mouth of the mine is $1 70 per ton. A short distance N. W. of the Tatsau is a high cliff of porphyry, forming part of the edge of the porphyry hills that bound the Chaitang district on the west. This rock is said, by the Tatsau miners, to cut off the coal and its accompanying rocks.

The annexed wood-cuts (Figs. 2 and 3) serve to give some idea of the Tatsau mine.

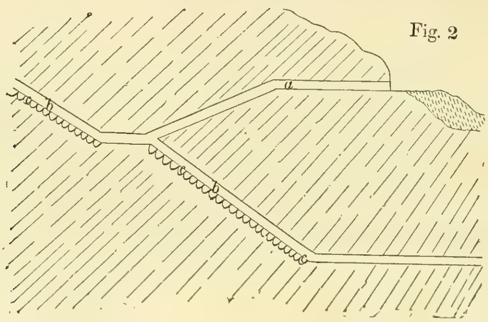


Fig. 2

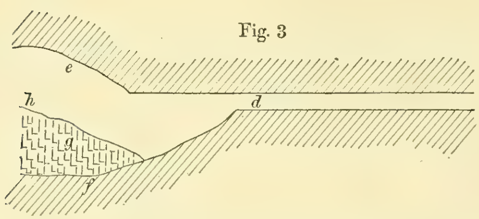


Fig. 3

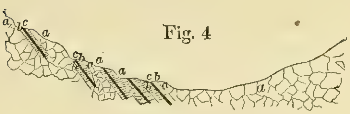
The entrance is by the gallery a, at first horizontal, then rapidly descending to the inclined shaft b. These are in the smaller and lower seam. A drift leads to the level d, Fig. 3, in the larger seam. In working the coal the miners drive a level, as far below the surface as the amount of water will permit, and extending horizontally along the foot wall as far as the limits of the mine, with a breadth equal one-half of the seam when this is less than twenty feet. Beginning at the end h, they excavate the coal below the gallery, at f, to a depth of from ten to twenty feet. When this has advanced a short distance they break down from the

[1] See Appendix No. 2.

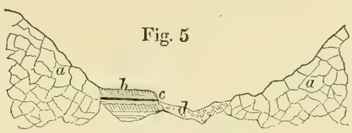
top e; and working back the coal is won from above and below the gallery at the same time, the refuse small coal, here about four-tenths of the whole, serving as a support g, in place of that extracted. The water is carried out by the inclined shaft b, fig. 2, the work being done by blind men, one of these standing in each of the hollowed out steps c, and bailing the water from his step to the one above him.

The coal is drawn out on sleds, by men, through b and a, only one-half the breadth of b being cut into steps for drainage.

Chingshui Mines.—These mines are in a narrow valley, about five miles W. N. W. of Chaitang, in the midst of the porphyry mountains. There seem to be several seams, but the confusion caused by the numerous dykes of porphyry is very great. In two of the seams the roof is formed by these dykes, at least for a considerable distance, while others are cut through by them, and in places only fragmentary portions of a seam, and its accompanying beds are left. Fig. 4 gives a general idea of the relation between some of the seams, and the porphyry as seen in the side of a mountain valley. Fig. 5 is a section of a fragment of the coal series only a few square



a. Porphyry. *b.* Coal series. *c.* Coal seams.



a. Porphyry. *b.* Coal series. *c.* Coal seam. *d.* Creek rubble.

rods in extent, cut off on one side by the porphyry, and on the other by the creek. The coal of this locality is very bituminous, and I failed, during my short visit, to find any indications of the metamorphism, often observed in the action of dykes on coal, especially where basalt has broken through tertiary brown coal formations.

The coal of the second seam from the right, Fig. 4 c,[1] is very brilliant, clean, and firm, breaking with a cubical fracture. It is very inflammable and melts and cakes, burning with a long flame, and leaving considerable ash.

Spec. gr.	1.38
Parts of lead reduced by one part of coal	29.00
Units of heat	6670.00
Percentage of ash	12.00

The seam from which this coal was taken had been worked about 500 feet on an incline, until stopped by water, and averaged between 7 and 8 feet in thickness. The fuel was best in the middle of the seam, and improved with the increasing depth. The proprietor worked two shifts of thirty men each, viz., eight miners, six carriers, ten water raisers, four men at mouth of mine, and two overseers. One miner produced, per shift, 1500 catties (about 1900 lbs.), of which two-thirds was coarse coal, and one-third fine.

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[1] See Appendix No. 2.

The fuel, from this place, is almost all used in the tile-glazing establishments of Peking.

Porphyries.—In the mountains north of the Wangping coal basin, the limestone has been much disturbed by the intrusion of porphyry, which, in some places, traverses it in the form of large dykes, and in others rising under it in large dome-like masses, causes the overlying strata to dip from these in all directions.

As the porphyry conglomerates, at the bottom of the Coal series, are mostly derived from these rocks, their eruption took place before the Coal measures were deposited. Two varieties of felsitic porphyry were observed here, both younger than the limestone, and both represented in the conglomerate. One of these forms dykes on the ridge of Hiamaling and along the Hun Ho, between this ridge and Chingpaikau. At the first-named place, it incloses immense fragments of the black clay slate that divides the upper and lower members of the limestone.

This porphyry contains, in a compact, slightly greenish base, a little green mica and numerous crystals of a triclinic, milky-white and slightly opalescent feldspar, and is free from visible quartz. The feldspar weathers yellowish-red, and the base dirty-white. The rock strikes fire with the steel, though not very readily.

Near Yenchi, on the Hun Ho, a few miles below Hiamaling, is the second variety. It contains, in a light-pink base, crystals of feldspar, apparently orthoclase, and no visible quartz. The porphyry that cuts off the coal rocks near the Tatsau, is probably younger than the Coal measures, although it is uncertain whether it occurs in that locality as a dyke, or whether it is brought into the position it there occupies by a great fault.

This rock has, in a compact gray base, tending to green, numerous prisms of hornblende and small crystals of white feldspar, some of which at least are triclinic. It contains no visible quartz, and strikes fire with difficulty. Thus its characteristics are those of a hornblendic porphyry.

At Chingshui, two varieties of porphyry were observed, both traversing the coal rocks. In one of these, the base is black and fine-grained, containing numerous minute and small crystals of a transparent, colorless feldspar, certainly for the most part triclinic. There is no visible quartz, and the rock strikes fire with difficulty.

About ten miles S. E. of the entrance to the Nankau pass, near the granite point that juts out into the plain at Yangfang, there is an extensive fault in the limestone, the strata of this rock dipping toward the fault. Between the line of this fault and the granite there is a broad dyke of quartziferous porphyry. In a fine-grained pink base, it contains crystals of pink orthoclase and abundant grains of quartz.

It may not be out of place to mention here the coal districts of Muntakau and Fangshan. The former of these forms part of the Wangping basin where this disappears under the plain of Peking. The valley of Muntakau forms in itself a small bay, containing terraces of the plain deposit; there are said to be thirteen seams of anthracite in the sides of the valley, most of which have been worked since during the Ming dynasty.

Those seams which I visited alternate with sandstones and argillaceous shales, and underlie the peculiar green quartzose conglomerate that characterizes the lower part of the Chaitang series.

The Tehyih mine seems to be the most important, and has been worked for a horizontal distance of 8,500 feet. The seam is very irregular in thickness, varying from a mere thread to six or seven feet, and as much so in strike and dip. The anthracite is dull and hard and made up of layers. It flies to pieces in burning.[1]

Spec. gr.	1.79
Parts of lead reduced by one part of coal	31.00
Units of heat	7130.00
Percentage of ash	7.00

In this mine one miner produces on an average only about 100 catties—133 lbs.—daily, and the loss of time in bringing the coal to the surface is very great, the man who drags the sled being obliged, from the lowness of the gallery, to go on his knees the entire distance of more than a mile and a half. The men protect their knees and hands with cushions, a precaution of which I was able to appreciate the value after having gone in about 5,000 feet and back without any such protection. The galleries grow smaller as the mine grows older, for, in replacing the old timber it often happens that the miners dare not remove an old piece, but are obliged to place the new one under it, and in this way the lapse of time reduces the height of the only thoroughfare of the mine. I was surprised on seeing at the entrance a very large fan-blower, made much like the machines used for fanning rice (which, in turn, are the same as our own fanning machines), and which is used here for ventilation.

In the district of Fangshan all the coal is said to be anthracite. Several seams are traversed by the galleries of the Yingwo mine, the lowest seam being only about 150 feet above the limestone, the intervening beds consisting of argillaceous shales, and the whole apparently conformably stratified with the limestone. The strike of these beds is E. W., and the dip about 30° to N. The lowest seam, which furnishes the most of the production of the mine, is very irregular, varying in thickness from one to thirty feet. The anthracite is very friable and flaky.[2]

Spec. gr.	1.86
Parts of lead reduced by one part of coal	27.70
Units of heat	6371.00
Percentage of ash	15.00

At Changkauyü, about eight miles W. by N. from Fangshan, is the Tashhitang mine, which is interesting as showing the manner in which the Chinese work on a large scale. The inclination of the seam varies from 50° to 90°, and the thickness from one to thirty feet, the average being estimated at six feet. The coal is called *haimé*, *i. e.*, black coal, and is a hard, lustreless anthracite, in layers with irregular fracture.

Spec. gr.	1.80
Parts of lead reduced by one part of coal	31.50
Units of heat	7245.00
Percentage of ash	5.50

[1] See Appendix No. 2 for better analyses.
[2] See Appendix No. 2.

The workings extend to a horizontal distance of about 6,000 feet, the drainage being effected by a fault, and the ventilation by an opening through old workings to day-light.

The mine is entered by an inclined gallery, descending in the seam, at an angle of about 30°, till near the water level. From the foot of this a horizontal or slightly rising level is driven in the coal to the extreme limit of the intended mine, in this instance over 6,000 feet.

In extracting the coal only those portions of the seam are worked which are sufficiently thick to admit the miner without cutting into the walls.

The "winning" is conducted on the following general plan: where the coal is sufficiently thick, rising galleries are driven at an angle of about 30°, from the tops of which a level extends in both directions as far as the seam retains the proper thickness. From this level other rising galleries and a second level are driven, and so on till the whole enlarged part of the seam is opened, forming pillars twenty-five or thirty feet high, with a length that seems to be very variable. The timbering is now removed from the upper gallery, and the coal broken down from the roof, the miner working from a scaffolding. In this manner working from the farthest and uppermost pillars toward the main level the coal is all taken out, unless the extent of the enlarged part of the seam is too great, in which case pillars are left standing. The coal is all carried on basket-sleds to the main level, and through this to the surface. A great deal of timbering is used, chiefly the wood of fruit trees, etc., and costing at the mine twenty-nine cents per 100 lbs.

One miner produces on the average about 700 lbs. daily, his wages being thirty-nine cents. About four-fifths of the coal is a mixture of small pieces and powder. The owner of the mine considered himself able to produce between thirty and forty tons, of coarse and fine, daily. The price at the mine is $3.60 per ton (2000 lbs.) for the lump coal, and $2.00 for the fine, which is bought to make cakes similar to our patent fuel. The better varieties of the Fangshan coals are taken to a depot at the head of boat navigation on the Liuli Ho,[1] about twelve miles from Fangshan, where the selling price is about $5.50 per ton.

The better varieties of the Chaitang and Muntakau districts are carried on mules and camels to Peking, where the selling price of the former is about two and a half times the price at the mines.

So far as I could ascertain, all the coal worked in the district of Fangshan and in the eastern portion of the Wangping field is anthracite. The only instance of an intrusive rock that I observed in the Fangshan district, was west of the city,

Fig. 6

a. Granite. *b.* Fine-grained micaceous rock. *c.* Sandstone altered to quartzite. *d.* Limestone. *e.* Black clay-shale with four seams *f* of anthracite. *g.* Quartzose conglomerate. *h.* Creek alluvion.

[1] A tributary of the Peiho.

where a low ridge of granite runs N. S. and is succeeded on its western side by the vertical coal rocks, also trending N. S., while almost everywhere else in the district the strike of these last is E. W.

The preceding section is simply intended to show the relation of the strata to the granite.[1] The limestone *d*, is about 600 feet thick, and seems to be a member of the Coal measures proper. The black shale *e*, with its seams of anthracite *f*, is about 500 feet thick.

From the Plain of Peking to Kalgan.

As we approach the Nankau pass, through which lies the great high-road from Peking to Central and Western Asia, we find the edge of the plain deposit rising with a more rapid slope toward the bordering mountains, while at the same time, the firm, fine loam gives place to rolled fragments and gravel of limestone and granite, from the neighboring hills. The pass is reached by the transverse valley of the Nankau creek.

Leaving the plain, we pass between lofty cliffs of limestone for about six miles, before reaching the axial granite of the ridge. The trend of the strata, which is N. 60° E., with a dip of 40° to S. E. by S. $\frac{1}{4}$ S. at the edge of the plain, becomes irregular as we approach the granite, the beds being in places almost horizontal, and in others vertical and striking E. W. The latter case occurs at about two and a half miles from the plain, where a side ravine discloses a dyke of a black eruptive rock, inclosed between the strata to which its plane is parallel. This rock has, in a black compact base, thin transparent crystals of amber colored triclinic feldspar. The dyke is only a few feet thick, and is made up of transverse columns. Near the grand marble arch of the Küyungkwan, the limestone is cut through by red porphyry, which is itself traversed by a greenstone dyke. The porphyry contains a little quartz, green mica, and crystals of orthoclase in a compact pink base. The greenstone is apparently a fine-grained diorite.

The granite of the Nankau pass consists chiefly of large crystals of flesh-colored orthoclase, black mica, and comparatively little quartz, with crystals of white triclinic feldspar. Near the middle of the pass there is a different and somewhat remarkable variety, almost free from mica, and consisting of pearly white orthoclase and gray quartz in nearly equal proportions. It is slightly cellular, containing prismatic crystals of white and smoky quartz in the small cavities.

The first of these varieties is traversed near Chatau by dykes of a pink rock, consisting of a fine-grained mixture of orthoclase and quartz with very little greenish mica—one of those rocks that form the link between quartziferous porphyry and true granite. These dykes are in places crossed by others, probably of diorite, consisting of a fine-grained mass of hornblende and feldspar.

The ridge we have just crossed extends to the S. W., forming, in Shansi near the Chihli boundary, a series of high peaks which, on the 26th of April, 1864, were

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[1] Unfortunately most of the specimens and notes from this interesting locality were lost.

covered with snow, rendering their great domes visible from the valley of the Yang Ho, towering above the mountains that occupy the intervening space of sixty or eighty miles. From the low Nankau pass, we descend to the Kwei Ho, a small tributary of the Yang Ho, which occupies a broad N. E. S. W. valley.

High terraces of a recent lake-deposit occupy the greater part of the valley, concealing the rocks and resting at Chatau on the granite. About a mile west of Chatau rise small hills of a porphyry conglomerate, in beds trending E. N. E. and dipping to N. N. W. about 40°. As we go toward Yülin the fragments and rubble on the surface consist of porphyry, granite, and some limestone.

Descending from the lake terraces and crossing the flats of the Kwei Ho we reach Hweilai (hien), situated on the terrace that fringes the northern border of the valley. Within the walls of this city limestone is seen to crop out in beds trending nearly N. E., and dipping to N. W. Going N. W. from here, over the terrace, the only index to the structure of the neighboring hills is in the angular and rounded fragments on the surface, and these consist of hornblendic gneiss, granite, quartz, porphyries and limestone till Shachung.

Between this city and the town of Sinpaungan the hills consist of the Coal measures, resting on the limestone, which here dips N. W. into the mountains called Papaushan. (See sect. Pl. III.) Between the coal rocks of this mountain and the remarkable limestone hill Kimingshan, there is an anticlinal basin filled with gravels of the lake terrace deposit, and formed by the erosion of an anticlinal fold of the limestone.

In the Kiming mountain the limestone beds are almost vertical, and so highly metamorphosed that in places the rock is almost flint, and their trend has changed to N. S. On the western side of the hill are the vertical strata of the Coal measures with seams of anthracite of poor quality, that have long been worked. The coal rocks of Kiming bend around the northern end of the hill, and extend away to the east, while on the other side of the Yang Ho they seem to extend up the valley of the Sankang Ho.

Crossing this small field to the northwest along the Yang Ho, we reach a deep gorge, through which the river traverses the limestone ridge that forms the northern border of the coal basin. In this gorge the limestone trends N. 70° to 75° E., dipping 25° to S. by E. $\frac{1}{4}$ E. Near the village of Hiangshui (pu), at the N. W. end of the gorge, the limestone suddenly ceases, and an open country of low hills of a peculiar rock, an amygdaloid, succeeds to the high ridge of limestone. Near the line of contact, the limestone trends as before, E. by N., dipping to S. by E., while the beds of the amygdaloid have the same trend, but a northerly dip. Here we seem to be on the line of an immense fault, for, although the fault itself was not seen, everything seems to point to it. The amygdaloid contains fragments of limestone, and strongly resembles in every respect a similar rock, which we shall see further on, forming a member of the Kiming Coal measures. This slip must have been extensive, as the limestone cliffs seem to be nearly 1000 feet high. The amygdaloid, corresponding apparently to the Schalstein of the Germans, is, perhaps, a tufa of the greenstone-porphyry that occurs in it in fragments.

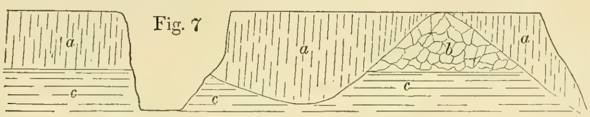
We soon emerge from these hills upon the plains of Siuenhwa (fu), which occupy

another enlargement of the Yang Ho valley, and are also lake terrace deposits. The road lies over this lake bed till about ten miles N. E. of the city of Siuenhwa (fu), where a spur extends westward from the mountains. This spur consists of a double ridge, with an intervening longitudinal depression, the southernmost portion being formed by beds, highly inclined to N. and trending E. W., of quartzite, red argillaceous sandstone, and a compact white rock, apparently an altered argillite. These beds, which seem to be the equivalent of the great limestone formation, will be referred to again in discussing the Hwaingan strata.

The northern part of the double ridge is a remarkable porphyry, which has either traversed or overlies the last mentioned beds. This rock may be called the Kalgan[1] porphyry, as it is extensively developed around that city, although it occurs also in the hills of the Gobi desert. It belongs to the trachytic series.

On the southern flank of this spur the lake deposit rises rapidly toward the hills, and the firm loam, of which it here consists, is cut into by deep gullies. In one of these places a section is exposed of horizontal beds, apparently the tufas of the

Fig. 7



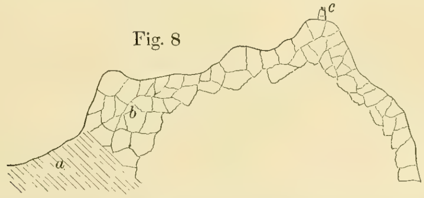
a. Terrace loam. *b.* White tufa. *c.* Red tufaceous sandstone.

Kalgan porphyry. The effects of an erosion previous to the deposition of the lake loam are visible.

We shall find similar tufaceous deposits intimately associated with the Kalgan porphyry near that town.

From the spur we have been examining we follow the road over the lake deposit, to Kalgan, or Changkiakau. High and rugged hills of the trachytic porphyry inclose the valley on the east, while to the north lies a higher range of mountains, which, as it forms a geographical as well as political boundary, and represents approximately the line of the Great Wall, we may call the Barrier range.

Fig. 8



a. White and red tufas. *b.* Kalgan porphyry. *c.* Tower of the Great Wall.

At Kalgan this range is traversed by a gorge, with vertical walls, through which a small stream finds its way to the Yang Ho from the edge of the Mongolian plateau.

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[1] The Russian name for Changkiakau, an important market town and gate of the Great Wall.

Here is the most important gate of the Great Wall through which pass all the caravans to Russia, and nearly all those that trade with Western Asia.

The mountains here consist of the tufaceous rocks of the Kalgan porphyry, which are traversed by dykes, and contain beds, of the parent rock. The portions of the range where this formation predominates are easily distinguished from those consisting of the usual granite and metamorphic schists, the latter forming pyramidal hills, while the former have the castellated appearance that is given by cliffs and dykes. The white and red tufas form low hills west of Kalgan, and in the wall of the gorge, in the Barrier range, beds of these rocks trending E. W., and dipping about 45° to N., seem to extend under the porphyry, Fig. 8.

CHAPTER IV.[1]

STRUCTURE OF THE SOUTHERN EDGE OF THE GREAT TABLE LAND, AND OF NORTHERN SHANSI AND CHIHLI.

Two roads, slightly divergent, lead from Kalgan to Urtai on the plateau. About a mile and a half from the town, on the east road, the trachytic porphyry formation appears, under circumstances that would seem to show that much of it is of pluto-neptunian origin.

This formation extends several miles further north and northeast till it is limited by the metamorphic schists of the range. On the west road the same formation exists till near Tutinza, on the northern side of the range, and furnishes slabs of tufa and blocks of porphyry for building purposes.

The country crossed by the road between the Barrier range and the edge of the plateau is a depression, here about nine miles broad. On either side of the road are flat-topped hills 80 to 100 feet high, of gravel made up in great part of rolled fragments of quartziferous porphyry. This gravel, which I take to be of the same age as the lake loam and terrace deposits, also forms the low hills traversed by the eastern road, where it covers a brown-coal basin probably of tertiary origin, of which, unfortunately, I was able to see only specimens of the coal.

About half way between Tutinza and Hanoor the road begins to rise to the plateau, and leaving China proper, with the edge of the table-land, we reach the steppes of Tartary.

The height of the edge is here 5,400 feet above the sea, according to the measurement of Fuss and v. Bunge, and probably not less than from 3,000 to 3,500 feet above Changkiakau, and the edge itself forms a precipitous wall to the south, while the plateau slopes off gently to the north.

From a tower of the Great Wall, which crowns a hill near Hanoor, we have, spread out before us, a grand panorama of the surrounding country. The natural wall formed by the abrupt termination of the table-land stretches away from the tower far off to the west and northeast, bounding the valley south of it as a precipitous coast bounds the sea. Between us and the Barrier range, the depression, occupied by low hills of the eroded gravels, lies like a neutral belt between two regions of the earth in almost every respect widely different each from the other. To the south only barren and rugged mountains meet the eye, and beyond these to the Southern Ocean, the mountainous character is redeemed only by the fertile valleys of a few

[1] For this Chapter see Map, Pl. No. 2, and Sections, Pl. No. 3.

large rivers. To the north lie the endless plains of Tartary rarely crossed by other than low ridges.

At the point where the road begins to rise to the table-land, we enter upon the volcanic formation of Southern Mongolia. From the base of the plateau-wall to the summit, we may look in vain for other than the rocks of this formation, and as we travel westward we shall see little else while on the plateau.

Our road now follows a general westerly course, keeping near the edge of the table-land. The surface of the plateau along this route is everywhere cut into by valleys varying in depth from one to several hundred feet. The tops of the hills thus formed are flat, and in the same plane—that of the original plateau surface—excepting where the erosion has isolated small hills, in which case they present knobs lower than the general plane. The sides of these hills form in places cliffs, but more generally they slope off to the valley bottoms. The width of the valleys varies from a few hundred feet to three or four miles, the smaller ones sometimes narrowing to a gorge, and again reopening to their usual size. They frequently form fertile meadows with brooks winding through them, and are then the camping grounds of the Mongols, and the pastures of their large herds of sheep, horses, cows, and camels. The pasture is not confined to the bottoms, the whole country, hill and valley, being clothed with excellent grass.

Soon after leaving Hanoor we reach a small lake, or rather pond, without outlet, inclosed in the depression between several knobs. It is difficult to understand how these small depressions are formed, unless we suppose them to represent former inequalities in the bottoms of valleys once occupied by running streams. Such small lakes are characteristic of Mongolia, and we shall have occasion to notice several.

Continuing westward, the road passes the lama-monastery of Boroseiji, and ascends the grassy valley of a small tributary of the Narin Gol.[1] This stream rises at the very edge of the plateau, flows N. E. by Urtai, and turning to the south descends from the plateau at Teutai, and passing through the gorge at Changkiakau, joins the Yang Ho.

Leaving the system of this stream, we pass over a ridge, part of the original plateau, near which is a hill rising several hundred feet above us, consisting, to judge from fragments on the surface near by, of chloritic gneiss. This is an isolated peak, rising through the volcanic formation which has buried the rest of the ridge.

Descending to the west we enter another fine valley, apparently that of a tributary of Angouli Noor.[2] Through this valley flows a creek which, near the Mongol village of Hanoortai, widens to a small lake, the abode in summer of thousands of wild ducks. From this valley the road passes over a low ridge and descends by a narrow, rocky defile to the plain of Taulichuen, in which is the source of one of the tributaries of the Yang Ho. We have here left the plateau, and are among the cultivated fields of the Chinese,[3] but we are still on the volcanic formation.

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[1] Gol, Mong. for river. Wherever this word occurs in this itinerary it refers only to small brooks.

[2] Noor, Mong. for lake.

[3] The Chinese are forbidden by law the cultivation of land on the plateau.

Leaving this plain, we again rise to the table-land, and following, for six or seven miles, its abrupt edge we come again to a sudden descent by which we leave it and enter upon a rolling country. The plateau wall makes here a great bend, trending away to the northwest.

The country over which our road now lies is a rolling plateau formed by a broad swell, or ridge, of the granitic and schistose rocks, from which the volcanic plateau covering has been eroded. On it are the sources of another tributary of the Yang Ho.

The rocks are granite, syenite, and crystalline metamorphic schists.

This bay-shaped indentation of the southern edge of the plateau is about 15 or 20 miles broad; it is drained in part by a valley descending toward the southwest, and is surrounded on the east, west, and north by the wall of the higher plateau. The northern portion of this bay forms a depression that is only partially drained, and which at times is evidently a marshy region, while it contains at all seasons three small lakes—Gurban Noor. In April the country about these lakes was covered with scattered tufts of grass, between which the dry clayey surface was white with an efflorescence of soda, and the borders of the lakes also were incrusted with a dazzling layer of the same salt.

About two miles west of the Mongolian camp of Gurban Noor, the higher table-land again begins, but with a somewhat different character. Rising to the top of a granite ridge, we descend a little on the west into a plateau-valley. On either side and before us are everywhere the same flat-topped hills we have seen forming the table-land, but they are only the remnants of a volcanic covering insignificant in thickness compared with that we have seen farther east. The valleys have everywhere cut through this covering and into the granito-schistose foundation.

Our road now lies through a succession of circular and oblong meadow-valleys, connected by narrow outlets, thus forming one valley-course, and containing a small brook, the Hoyurtoloho Gol, which flows S. E. The meadow enlargements are evidently the beds of small lakes filled with the detritus of the surrounding volcanic and granitic rocks.

Following this valley in a general S. W. direction from the Mongol camp, Hoyurtoloho Gol, we descend through a narrow defile in chloritic granite, into another bay cut out of the plateau, and open to the S. E., where the drainage finds an exit through the valley of the Si Ho, another tributary of the Yang Ho.

Soon after leaving the gorge, by which we have descended, the road crosses a lava stream one or two thousand feet broad, and from sixty to eighty feet thick, which crosses the valley, and is cut through by the rivulet. In this section it shows columnar structure, and is in places porous and amygdaloidal. A mountain forming apparently a detached portion of the neighboring plateau, and having the appearance of a half-destroyed crater, seems to be the origin of the stream. The eruption causing this occurrence must have been subsequent to the erosion of this part of the plateau, and was probably subaerial. The locality is interesting as being the only one in which I noticed traces of true volcanic action more recent than that to which the volcanic formation of Southern Mongolia owes its origin.

Crossing the valley of the Si Ho, which leaves this bay-shaped depression at the

S. E., we enter another valley opening in the S. W. Frequent fragments of a calcareous deposit strewed over the surface indicate the action of mineral springs.

Gradually ascending this valley, which, as well as that of the Si Ho, is occupied by a deposit of loam, probably contemporaneous with the terrace loam of the Yang Ho, we reach a point where this loam deposit, by forming a bar across the valley, causes a low watershed, on one side of which any drainage there may be flows north to the Si Ho, and on the other south to the undrained lake Chaganoussu.

We shall see that this remarkable occurrence of alluvial watersheds stretching across valleys is intimately connected with the formation of the undrained lakes of this portion of Mongolia, having its origin in a former system of great inland lakes, and its continuance in the dryness of the climate.

The grassy valley of Chaganoussu has two other openings through the plateau, one on the east connecting it with the Si Ho valley, and another on the west leading to the Kir Noor. Both of these are crossed by bars covered by the terrace loam, if not entirely formed by it. Our road, after skirting the shallow pond of Chaganoussu enters the valley leading to the southwest, and passing the dried up bed of the Hoyur Noor descends through a narrow defile till it emerges into the great depression of the Kir Noor.

From the Si Ho to this point the rocks, both of the adjoining plateau and of the exposed parts of the valley bottom, belong throughout to the volcanic formation.

From the edge of the plateau, near where the road enters the Kir Noor valley, a view of the whole of this ancient lake-bed is spread out beneath us. It is a large plain about 15 miles broad, its longer axis trending about N. N. W. On both sides the lofty and bold plateau edge is seen stretching away to N. N. W. and S. S. E., as far as the eye can reach, without meeting to inclose the valley.

Away to the southwest of us a distant portion of the plain covered with a dazzling white efflorescence marks the position of the Kir Noor of a few years since. From this, the most depressed part of the plain, the surface rises toward every point of the compass. Far away to the north a bar of the lake deposit seems to stretch from wall to wall of the valley, while in the south this is certainly the case. Over this southern alluvial bar the peaks of the Barrier range are seen in the distance.

To the N. N. W. a distant peak, capped with snow (April 18th), is visible rising above the level line of the table-land.

The edge of the plateau on both sides of the valley, wherever I visited it, consists of the volcanic formation, from the summit to under the lake deposits, but the presence on the surface of the latter of granite detritus indicates the presence of the older rocks at no great distance.

East of the Mongol village of Hoyurbaishin, a gully exposes a section of the plain deposit near where this abuts against the edge of the plateau. The deposit is stratified, and its beds have the same dip as the surface of the plain. It consists of coarse sandstones and fine conglomerates, formed from the detritus of the neighboring volcanic rocks and cemented by a calcareous mineral, the product, perhaps, of springs, which enveloping each grain or pebble with concentric layers produces a hard rock. The only trees seen in the valley of the Kirnoor were two old ones

growing in this gully, nor did we meet with any others either on the plateau or in its valleys.

The lake is said to be drying up, and the Mongols say that its waters have flowed into the Té Hai farther west, an apparently unfounded belief, as there is no surface communication between the two lakes, and the natives on the shores of the Té Hai were not aware of any increase in its volume. Still it is evident that the waters of the Kir Noor are rapidly disappearing, and the cause, whether this be only temporary or a constantly operating change in the climate, has been acting for at least several years. Among the lakes we have already noticed, the Chaganoussu is also disappearing, and the adjoining Hoyur Noor has for several years been represented only by its dry bed.

The greater part of the plain of the Kir Noor valley is clothed with grass, and supports large herds of sheep, but as we approach the recent lake-bed the surface is eroded by dry, shallow water-courses, and is covered with tufts only of grass, between which the ground is bare and cracked. This was apparently a marsh surrounding the lake of which, a little further west, the dry bed is visible covered with the white soda efflorescence, and stretching several miles west, north, and south.[1]

The walls of this great valley, formed by the abrupt edge of the plateau, are marked by a series of lines at different heights, and extending apparently horizontally, and on the same level, along the faces of both sides of the valley. They are reproduced on an island-like hill that rises from the plain, and are visible at a distance of from ten to twelve miles to the naked eye. They are defined, where the slope is gentle, by a continuous mass of large and small fragments of rock, and on the steep declivities by slight variation in the angle of slope.

I was able to examine these lines in only one locality, and there they appeared to be independent of the structure of the plateau, and I can account for them only on the supposition that they mark former water levels.

Following the road from Hoyurbaishin to the Té Hai we cross, at about the middle of the valley, a small stream of fresh water flowing from the north, and which is seen to empty into the remnant of the lake a mile or two south of the road. Still farther west the road lies through a marshy tract. Two or three miles west of this we reach a terrace of the lake-deposit, which descending rapidly from the western side of the valley, faces the plain with a bluff. As the road ascends a ravine in this terrace, the increasing proportion of fragments of granite and gneiss shows that we are in the neighborhood of a rise in the granite foundation, while a few miles to the north a ridge rising several hundred feet above the level of the plateau, seems to be the source of the fragments in question.

As we leave the terrace and the valley of Kir Noor, we pass a deep and gloomy gorge cut through the plateau to its very foundation. Where seen it is barely separated by a low ridge from a valley that leads into the Kir Noor. This chasm seems to lead to the Karaoussu, a tributary of the Tourgen Gol, which is an affluent of the Yellow river. The valley by which we leave the plain leads us in a S. S. W.

[1] For the results of an examination of the dried mud of the recent lake-bed, see Nos. 1 and 12 in Mr. A. M. Edwards' Letter, Appendix No. 3.

direction gradually ascending, the flat-topped hills of the table-land shutting us in on both sides, till we reach a watershed from which we look down on a large, deep, circular valley, covered with grazing herds, and ornamented with the gilded spires of a lama-temple. This valley is shut in on the north and west by the volcanic formation of the plateau, but its southern wall is of granite and garnetic gneiss, capped here and there by thin remnants of the plateau mantle. Still farther south, after passing the village of Yingmachuen the plateau formation predominates, and the long descent into the valley of the Té Hai[1] is entirely over its rocks.

The great depression of the Té Hai is about twelve miles broad, and so far as the plateau is concerned, appears to be open to the S. W. in the direction of its longer axis. The northwestern side is formed by a serrated range of mountains, which rises about 2,000 feet above the lake, between this and the plateau. The eastern wall is of gneiss capped with the volcanic plateau formation, and the same would seem to be the case with the southern wall, while, as we have seen, the northeastern side is volcanic in its entire height. Thus the thickness of the volcanic mantle varies, within a few miles, several hundred feet.

The northeastern end of the valley contains an extensive deposit of the terrace loam. This faces the lake with a bluff that stretches N. W. S. E. across the valley.

From this line the terrace rises toward the N. E. at first gradually, and then rapidly, until in the long northeastern arm of the valley and in the side valleys, its surface is several hundred feet above the lake.

Below this terrace a plain rises gently from the lake toward the mountains.

The terrace deposit is a firm, stratified loam, containing, near the hills, numerous fragments of the neighboring rocks and layers of gravel. It is cut into by deep ravines, in the sides of one of which, about five miles east of the lake, I found several species of fresh-water univalves.

The lake is apparently about eight miles long by four or five broad. Its water is salt, though far less so than seawater, and is not bitter. The flat surrounding it is covered with a thin coating of soda efflorescence.[2]

While the valley of the Kir Noor is occupied exclusively by the Mongols and their herds, that of the Té Hai is cultivated by Chinese, only one or two Mongol camps being seen. Ancient watch towers, that dominate these plains, and from which signals could be made to the long line of similar posts on the Great Wall, are silent monuments of a time when the shores of these lakes were the home of an aggressive race, ever threatening a descent into the fertile regions of China. Rising with the terrace, the road leads us to the hills that form the southeastern wall of the valley, and we pass through these by a deep and rocky ravine, in which the pass is situated. These hills are, as I have already said, of gneiss, characterized by an abundance of garnets, and capped with the volcanic mantle. The stratification trends, in the main, N. E. and dips 75° to N. W. Garnetiferous granulite, from these

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[1] Daikha Noor of the Mongols.

[2] For negative results of a microscopical examination of the deposits, both of the terrace and the flats, see Nos. 2 and 3, in Mr. A. M. Edwards' Letter, Appendix No. 3.

hills, occurs in the terrace deposits on their N. W. flank. From this hill we descend into a small valley which empties into that of the Té Hai. In this valley the terrace loam is present to the height of probably not less than 250 feet above the lake.

From here the road descends to the deep channel cut through the plateau, which connects the great valley of the Té Hai with that of the Sankang Ho. This channel is cut to the bottom of the volcanic mantle, here apparently over 1,000 feet thick, and into the metamorphic rocks on which it lies.

In this channel we meet with another of those remarkable watersheds of terrace deposit which stretching from wall to wall, slopes on the west toward the Té Hai, and on the east toward the valley of the Sankang Ho. The material forming this bar is almost loose sand mixed with fragments from the volcanic and metamorphic rocks, and is but little, if at all, eroded on the western flank, while there are gullies on the eastern in which highly inclined beds of granulite, containing garnets, are exposed.

At Maanmiau the valley opens to form the broad, swampy plain of Fungching, rising from which are frequent low hillocks of gneiss in strata trending between E. and N. E. Here the high plateau leaves the road; the part that has formed the southern side of the valley since leaving the Té Hai, now trends away to the S. S. W. till the steep face and level outline of its edge are lost in the far distance. On the other side, the part which has formed the northern wall of the valley, continues a few miles farther, and then, before reaching Fungching, bears away to E. N. E.

Although we have here left the higher plateau, we have not yet reached the southern limit of the volcanic formation. At a level of perhaps 1,000 feet below the surface of the higher plateau begins the lower plateau, the flat surface of which is 200 or 300 feet above the valley, and extends southward from the very edge of the higher. It consists of the same volcanic formation as the higher table-land of which it was, I think, without doubt, once the continuation, the continuity having been broken by an immense fault—a supposition to which I shall recur further on.

The marshy plain of Fungching is fringed in places with low, flat hills, which owe their form to the terrace deposit of loam, but under this, consist of a bright red, sometimes loose material, apparently a wacke or a product of the decomposition of the volcanic rocks. In this are fragments of a red calcareous mineral, a product of the action of waters on the adjoining rock before or during its alteration. We shall see a similar mineral filling crevices in the volcanic plateau formation. It is perhaps the result of the metamorphic action of mineral springs rising along the great fault-line.

A few miles beyond Fungching our road rises to the surface of the lower plateau, and we obtain an open view from a ruined part of the Great Wall. To the north we can see the precipitous edge of the higher table-land stretching far away to the northeast, the break in it formed by the valley of the Kir Noor, and its continuation beyond this toward the Si Ho.[1] To the south and east we see the barren crest and peaks of the Barrier range. Between the higher table-land and this sierra is the lower plateau on the southernmost spur of which we are standing. The valley we

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[1] In Mongol, Djookha Gol.

have followed from the Té Hai passes beneath us, and continues south to Tatung (fu) and the Sankang Ho; it is well watered and fertile.

Crossing this southern promontory of the lower plateau the road descends into the valley of Kwantung (pu), a depression occupied by another tributary of the Sankang Ho, and lying between the lower plateau and the Barrier range. This range and a spur from it, form the southern and eastern limits of the valley, and the lower plateau forms the northern side, while to the west it is open.

A quarry about half way up the edge of the plateau presents a good though limited section in the volcanic formation. In this quarry two beds are visible—a lower one of crystalline lava, which, toward the top, becomes porous and passes into a true scoria, and an upper bed of more compact lava. Crevices extending through both these beds are filled with a calcareous segregation.

The terrace deposit sweeps from the valley of Fungching around the southern spur of the lower plateau, into the valley of Kwantung, from the centre of which it rises rapidly up to the sides of the mountains, filling their ravines, to a height of several hundred feet above the middle of the valley.

From the mountains forming the northeastern side a low spur juts out, narrowing the valley, and in the space between the point of this spur and the southern wall of the valley there is another of those remarkable watersheds to which I have several times alluded. The terrace deposit rises from the west to form this bar (though without reaching a height at all comparable to that to which it rises on the mountain sides) and falls off again toward the southeast.

Crossing this bar, and descending toward the southeast, we traverse the Barrier range by a deep and narrow gorge about eight miles long, through which flows a small stream which, taking its rise in the northeastern part of the valley of Kwan tung, empties into the Yang Ho.

In this gorge the range is seen to consist of crystalline metamorphic schists, chiefly gneiss, hornblende gneiss, hornblende schist, and hypersthenite, in strata varying in trend between N. N. W. and N. N. E., the dip at the two ends of the defile being toward the centre.

The terrace deposit occurs in this gorge and its side ravines, high above the stream, and on emerging into the great valley of Yangkau it is seen rising from the plain with an unbroken surface high up the sides of the Sierra north of the Yangkau valley, while south of the mouth of the defile it exist only as terraces several hundred feet above the plain. The terrace deposit extends from here down the valley of the Yang Ho to form the plains and terraces of the enlargements of the valley at Siuenhwa (fu) and Shachung. But it is not confined to the present river systems, for east of Tienching (hien) it caps the lower part of the ridge between the valleys of Yangkau (hien) and Hwaingan (hien) forming a plateau of loam several hundred feet above the valleys.

Following the road from Yangkau to Tienching, we have on the north the Barrier range, a rugged sierra of which the barren peaks must be from 2,000 to 3,000 feet high, above the valley. Along the line where the terrace deposit terminates on the steep flank of the sierra, extends the now ruined Great Wall of China, with its towers and parapets, till at a point opposite Tienching it crosses the mountains to

extend northward to the high plateau. The southern side of the valley is formed by a lower ridge, beyond which higher mountains are seen, and over these the distant snow-capped[1] peaks, or rather domes, of the range south of the Sankang Ho.

Leaving the valley of the Yang Ho near Tienching, we cross over the terrace-capped ridge before mentioned, into the valley of Hwaingan (hien). To the north of the road in crossing, and north of the whole valley of Hwaingan, the hills are seen to consist of alternating strata of a bright red rock and of a harder rock, in anticlinal and synclinal folds. The fragments brought by streams from the hill forming the western part of the southern side of the valley, are gneiss and hornblende schist.

Following the Hwaingan creek to the northeast, the road approaches, near where it emerges into the valley of the Yang Ho, a fine section in the strata of the northern hills. Resting on gneiss are strata of highly metamorphosed rocks, the continuation of those we saw in the hills between Siuenhwa (fu) and Kalgan, and which for the present may be called the Hwaingan beds. The valley of Hwaingan trends N. E. by E., and this seems to be about the strike of the strata. In the exit into the valley of the Yang Ho, the Hwaingan creek flows through a gorge formed by the erosion, parallel to its axis, of an anticlinal ridge of the Hwaingan beds.

From this point our road crosses the valley of the Yang Ho, and brings us again to Kalgan.

KALGAN TO SIWAN AND SINPAUNGAN.

Leaving Kalgan the road runs in a northeasterly direction through a deep gorge, with vertical walls, in the Kalgan trachytic porphyry, and its pluto-neptunian deposits, as far as Ulanhada. At this village it leaves the valley of the main stream, and turning into a tributary valley, winds with this through the mountains, following an easterly course to the Roman mission of Siwan. For eight or ten miles we see only the rocks of the Kalgan porphyry, but before reaching the village of Siyin'sz, these are followed by the crystalline metamorphic schists, which in turn are succeeded, before we reach Siwan, by syenitic granite. This last is eruptive, dykes of it traversing the metamorphic strata, and the main body often containing fragments of the schists. This rock forms the mountains around and beyond Siwan.

From Kalgan to this point, and beyond, the terrace deposit occupies the sides of the mountains, and at Siwan its terraces form the sides of the valley to the height of from 200 to 300 feet above the creek, and its vertical cliffs show it to be a fine, compact loam. In it the Chinese excavate their dwellings in suites of apartments having doors, windows, and partition walls, all cut in the loam. The walls are simply plastered over to prevent the dust from falling, and in this condition they last as long, if not longer, than the ordinary houses built of sunburnt clay.[2] In the

[1] 26th April, 1864.

[2] These excavations are common wherever the terrace deposit occurs in Northern China.

course of these excavations, fossil remains of quadrupeds are obtained in considerable numbers, especially horns of deer.[1]

Leaving Siwan the road lies first southeast, then south, crossing two ridges of chloritic gneiss and chloritic schist, and descending into the large oval valley of Chauchuen. This valley is occupied by the terrace deposit. Our road ascends the ridge forming the southern side of the valley. On the northern flank are the crystalline metamorphic schists covered by limestone, and over this beds of porphyry breccia with dykes of eurite. The terrace deposit rises almost to the summit of this ridge on both sides. Descending through the deep gullies in the terrace loam, the road enters the valley of a creek that empties into the Yang Ho, just north of the Kiming mountain. From this valley we cross the ridge, by a low pass east of the Kiming mountain, into the valley of the Yang Ho, and descend to Sinpauñgan. The low pass is covered by the terrace deposit, and beneath this on the northern flank are the coal rocks of the Kiming field, among which I saw a greenstone porphyry conglomerate similar to that at Hiangshui (pu), and probably its equivalent.

The terrace deposit in the pass consists of loam with gravel and fragments of the neighboring rocks, and occupies a higher level than the terraces of the valley to the south.

I will now attempt a general description of the principal rocks met with on the above journey. I am well aware that the following description can have but a very limited value, owing to the absence both of chemical determinations and of closer observations of the modes of occurrence.

Granitic and Crystalline Metamorphic Series.

Distribution.—These two classes of rocks form either collectively or individually the main body of every ridge we have traversed. Of them consist the ridges that rise through and above the volcanic mantle of the plateau, and they form the foundation on which this rests wherever the foundation was seen. Indeed, they are the skeleton of this region, supporting the limestone floor of the coal rocks.

Granite predominates in the first range where we crossed it in the Nankau pass; in the other localities, if it exist, it is covered by the crystalline schists.

Unstratified Granitic Rocks.—The main body of the ridge between Nankau and Chatau consists of a granite containing two varieties of feldspar, about equally distributed in crystals varying from an eighth of an inch to three-quarters in length. These are pink orthoclase and a white triclinic feldspar. The mica is a dark green almost black, probably magnesian variety, and quartz is present in comparatively small quantity. It is thus a granitite.

Near the middle of the pass is another variety, of even grain, consisting of only white orthoclase and gray quartz, the latter often in sharply-defined, small prismatic crystals imbedded in the mass. It is somewhat remarkable from small cells in which

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[1] As all the fossils of any value had been sent to Paris previous to my visit, I was unable to obtain any that were worth examining. It is to be desired that those now in Paris will be determined and described in order to fix the age of the terrace formation.

ends and corners of small crystals of the constituent feldspar and quartz are sharply developed.

The hills immediately surrounding Siwan, in the Great Wall range, east of Kalgan, consist of a reddish-gray syenite composed mainly of orthoclase, some gray triclinic feldspar, crystals of hornblende, and a little quartz. Large crystals of orthoclase render it porphyroid. Near the contact of this rock with the crystalline schists west of Siwan, dykes of it are seen in the latter, while fragments of the schists inclosed in the main body of the syenite are additional proof that it is eruptive, and younger than the metamorphic schist formation. Fragments of this syenite are inclosed in the pluto-neptunian rocks of the Kalgan porphyry.

A syenite of medium grain, composed of slightly pink orthoclase and hornblende, occurs over a large part of the rolling land east of Murkwoching.

Fragments of a fine red granitite occur in the bed of the Yang Ho near Kiming, and blocks of a red rock composed of fresh, bright-red orthoclase and grains of a soft, talcose or steatitic mineral, thus approaching a protogine, are common in the Hwaingan creek. At this latter locality there are many fragments of a rock, consisting entirely of a coarsely crystalline, triclinic, feldspar, apparently labradorite, of a grayish tinge tending to blue and weathering white. It contains scattered crystals of a mineral resembling sahlite.

Crystalline Metamorphic Rocks.—The tilted and folded strata of these rocks form for the most part all the ridges we have passed over after leaving Chatau. In the hills northeast of Shachung are beds belonging to the chloritic series—white triclinic feldspar, quartz, chlorite, and magnetic iron—a variety of chloritic gneiss.

In the hills traversed by the road from Kalgan to Siwan, and south to Chauchuen, the predominating rocks are still those of the chloritic series. In the hills south of Siwan I observed chloritic gneiss—orthoclase, chlorite, and quartz—and schist of nearly pure chlorite. In the mountains between Kalgan and Siwan, another well-defined variety of chloritic gneiss occurs, in which the feldspar is, in great part, triclinic. Schists of the hornblendic series also play an important part in this region. They are composed of a greenish-white triclinic feldspar and hornblende, sometimes one of these minerals predominating, sometimes the other. The trend of the uplifts in this region, though irregular, seems to lie between N. and W.

Under the Hwaingan beds near Kiu Hwaingan, the metamorphic schists here represented by gneiss, lie with a remarkable approximation to conformability with these younger strata. This gneiss consists of orthoclase and quartz, and is very poor in mica, excepting on the surface of the slabs into which it breaks.

The Barrier range, where we cross it west of Yangkau, is formed mainly of schists of the hornblendic series. Among these are extensive strata of a rock composed of black hornblende, with strongly defined prismatic cleavage, abundant garnets, and a little white feldspar. Another rock occurs among these strata composed of a greenish-white triclinic feldspar associated with a little black mica, quartz, and hornblende.

The substructure of the plateau, southeast of the Té Hai, is of granulite and gneiss. The former rock is in places fine grained and schistose with minute garnets, but occurs more generally with a coarser structure, in which it is seen to con-

sist of white orthoclase and thin lenticular plates or bands of gray quartz, with abundant irregular grains of garnet of the size of a pea.

The gneiss of this locality runs through several varieties, all alike rich in garnets. Gneiss with garnets is also exposed under the volcanic beds at Yingmachuen, northeast of the Té Hai.

Thus where we cross the Barrier range west of Yangkau, we find the predominating schists to be of the hornblendic series. In the echelon to the east, between the Yang Ho and Hwaingan creek, the schists, that underlie the Hwaingan beds, are mainly of the micaceous series, gneiss being most common. The schists that are exposed west of the Barrier range, between this and the Té Hai, and at Yingmachuen, belong, as we have seen, also mostly to the micaceous series, gneiss predominating and alternating with its congener—granulite. The general trend of the uplift of these latter schists, in the region between Kiu Hwaingan and the Té Hai, is northeasterly and parallel to the course of the Barrier range, while the mean strike of the schists of the hornblendic series, in the main body of the range, seems to be north-northwesterly.

If we glance at the metamorphic region east of Kalgan, we find that its schists belong to the hornblendic and chloritic series, and here also the mean strike seems to lie between north and west.

Have we here to do with the metamorphosed strata of two distinct periods? It would be hasty to assume that such is the case in the absence of more data, but it does not seem improbable that the schists of the hornblendic and chloritic series represent deposits of an earlier age followed by N. W. S. E. foldings of the strata, while the gneiss and granulite series belong to a later epoch which was followed by the N. E. S. W. disturbance.

Hwaingan Beds.—These strata, which have already been referred to as resting almost conformably on gneiss, cover the hills on both sides of the Hwaingan creek, and occur with an easterly trend and northerly dip at the edge of the hills, N. W. of Siuenhwa (fu). They are made up of layers of compact and hard, gray silicious limestone, with quartzose sandstones, red and gray argillites, and quartzite. The predominating rock would seem to be the limestone. The aggregate thickness is several hundred feet. The lowest layers are, first, and resting on the gneiss, a fine grained sandstone, green from thin layers of a green mineral; over this, sandstone altered to quartzite; on this a red argillaceous shale; finally, silicious limestone containing numerous thin layers of chert. The alternating beds at the bottom of the series vary in thickness from six inches to many feet, and in the cliffs seen from the road, I noticed that they frequently thin out and dovetail into each other, an occurrence that seems to indicate frequently changing conditions of level and material.

The Hwaingan beds appear to be the equivalent of the great limestone floor of the coal-bearing rocks, and their character and thinness would seem to indicate that they were formed on the borders of the sea in which that great formation originated. The limestone of the Kiming basin is highly silicified, and its thickness seems to be much less than that of the same formation where it rises from beneath the great plain.

Greenstone-Porphyry Conglomerate.—The beds of this rock were noticed near

Hiangshui (pu), and also in the coal field of Kiming, where they occur apparently as members of the coal-bearing series, and at a higher level than the lower coal seams.

The fragments of porphyry that form the characteristic feature of this deposit, have a base that varies in texture, from compact to finely crystalline, in color from dark reddish-brown to black, and that effervesces slightly in dilute muriatic acid. It contains numerous thin, oblong crystals, of a white triclinic feldspar, from one-eighth to three-quarters of an inch long. Through the base are scattered grains of a white mineral, apparently a zeolite, and scales of what seems to be ichthyophthalmite.

In places, these fragments make up the greater part of the deposit, and it is then difficult to distinguish the inclosed from the inclosing rock. In other places the blocks are scattered through a finely crystalline, dark reddish-brown rock, that is irregularly impregnated with a carbonate, and about as hard as compact limestone. It contains also pieces of an amygdaloidal rock, the cells of which are filled with calcite and a white zeolite; blocks of limestone are also found in it.

The general appearance and manner of occurrence of this deposit suggests the idea that it is of pluto-neptunian origin, and perhaps contemporaneous with the eruption of the greenstone-porphyry. I will add that I did not meet with dykes of this porphyry.

Kalgan Trachytic Porphyry.—This rock, and its pluto-neptunian deposits form the hills around Kalgan, and those that, extending S. E. from that city, send out a spur to the west crossing the road from Siuenhwa.

The porphyry in question is very variable in color, the most common variety being brown, but all shades occur from pitch-black to white, red, and green. The texture of the rock is compact, often almost vitreous, but in structure it ranges from the solid rock of the Kalgan mountain to the cellular and often almost pumiceous variety of the spur between Kalgan and Siuenhwa.

Crystals of white, transparent orthoclase, or glassy feldspar, are always present, and are generally so limpid as to take the color of the variety in which they are imbedded. Small grains of pellucid quartz occur more rarely, but seem in places to belong to the primary ingredients, though they are generally secondary. Mica and hornblende are always absent.

The cells are sometimes long-cylindrical, but more generally flattened, though lying in the same direction. They are filled with different varieties of quartz, as cornelian, chalcedony, and a black silex. More rarely they are filled with calcite.

The base of this rock fuses easily before the blowpipe to a white vesicular glass on the edges.

In intimate connection with this porphyry are strata of a deposit which, from their character and manner of occurrence, appear to be of pluto-neptunian origin, and were probably formed contemporaneously with the eruption of the porphyry. These consist chiefly of a tufa, varying in color from white and gray to purple, and in hardness between that of chalk and limestone. Its texture is rough and earthen in appearance. Through the mass are scattered crystals of glassy feldspar, grains of limpid quartz, and hexagonal scales of dark-brown mica.

Beds of another rock occur, of brick-red and brown colors, and having an earthy base, with small, brilliant crystals of glassy feldspar and grains of pellucid quartz, and inclosing small fragments of other rocks.

This deposit is visible on the southern flank of the spur between Kalgan and Siuenhwa, underlying the terrace loam in horizontal beds (Fig. 7).

At the base of the high hill north of Kalgan the tufa beds are seen to dip under the porphyry at an angle of about 45° (Fig. 8), and trending west they form a series of detached hills. On the roads leading to Tutinza, Teutai, and Siwan, they are traversed by a perfect network of dykes of the porphyry, which rock also caps the summits of the hills, its vertical cliffs and outstanding dykes giving them a bold and castellated appearance.

Although no analyses of these rocks have been made, there is, I think, little doubt that we have here to do with a trachytic porphyry and its tufas.

Volcanic Formation of the Plateau.—The southern elevated edge of the Great Plateau is formed, between the 112th and 115th meridians, of an immense lava bed. How much further it extends beyond the limits given above, or how large its breadth may be toward the north, is unknown; I have only tried to indicate on the map the region which I observed it to occupy. Its breadth is, in places, not less than forty miles, and this may be only a fraction of the real width.

The thickness of the formation is, necessarily, very variable as it fills the inequalities of what was once a mountainous country. At Hanoor it seems to be not less than fifteen hundred feet thick, and the same may be said of it in other localities visited, while we have seen it in places represented by only a thin sheet, covering the metamorphic schists, where these rise to near the surface.

The rocks of this formation may be classed under two types—the one basaltic, the other trachytic.

The basaltic rocks were observed more particularly near Hanoor and to the N. E. of that place. Both compact and finely crystalline varieties occur. They are generally, especially the latter variety, poor in olivine and contain here and there crystals of basaltic hornblende.

At many places in the neighborhood of Hanoor, fragments of a cellular variety occur on the sides of the valleys, in a manner that would seem to indicate, that there is a horizontal bed of it, marking the plane of contact between two flows of lava.

The rocks of the other type are throughout crystalline, though often the texture is very fine, and are generally porous. In color they vary from black to dark gray, while some varieties, especially when weathered, are light gray. In some instances hornblende, or augite, enter abundantly into the composition of the rock, but more generally it seems to consist almost exclusively of white or yellow, triclinic feldspar with greasy lustre, partly in tabular crystals, partly massive. Scattered through this mass are minute specks or grains of a dark to light green mineral, with glassy lustre and conchoidal fracture, harder than the knife when fresh, soft and resinous in lustre when altered. The feldspar is probably oligoklas. A characteristic feature of the different varieties of this rock is the extreme rarity or total absence of magnetic iron.

This lava seems to belong to the trachydoleritic series. Of its varieties consist nearly the whole of that portion of the volcanic formation that was traversed by my route. That it obtained its great development on the surface by successive flows, is evident from the stratiform structure of this part of the plateau.

The only locality in which I observed an exposed section of comparatively fresh rock, was in a quarry at Kwantung (pu), on the lower plateau. Here a bed of lava, crystalline at the bottom of the section, becomes porous toward the top, and, finally, highly vesicular and highly scoriaceous, this structure marking the top of the flow. Above this is a bed of more compact lava than the lower. Crevices extending through both of these beds are filled with a calcareous segregation product.

I am unable to account for the occurrence of this immense lava formation, excepting by the supposition that the successive flows took place from an immense crack, the position of which is perhaps indicated by the great fault line along which the dislocation took place between the higher and lower plateau.

Terrace Deposit.[1]—The loam of this formation has been frequently mentioned in the previous pages. It occurs in the valley of every tributary of the Yang Ho and probably also of the Sankang Ho. It exists in the form of terraces between Chatau and Kiming, and these undoubtedly occur in the valley of the Sankang Ho from Paungan (chau) to Tatung (fu). Between the Kiming hill and the Papau mountain, a terrace of coarse detritus overlooks the valley of Hweilei (hien), its surface being several hundred feet above the Yang Ho.

In the valley of Siuenhwa (fu) this deposit seems to have suffered less from erosion, and rises, generally without terraces, at first gently then rapidly toward the bordering mountains, filling ravines high up their sides. Our road to the north lay over this deposit, as we skirted the hills between Siuenhwa and Kalgan, and we saw it fringing the Kalgan gorge with isolated terraces high above the river. Leaving this gorge, and ascending the valley of the Siwan creek, we found it in continuous terraces, which even at the Roman mission of Siwan, rise 200 or 300 feet above the creek.

Going southwest from Kalgan, we find this deposit continuous from the valley of Siuenhwa into that of Hwaingan, and we have already seen how it forms a plateau capping the ridge between this valley and the Yang Ho at Tienching. It is also undoubtedly represented along the Yang Ho from this place to Kalgan.

We have seen it, between Tienching and Yangkau, rising unbroken from the plain to high up the sides of the Barrier range, and continuous from here, in terraces, through the defile west of Yangkau into the valley of Kwantung (pu), and thence around the southern spur of the lower plateau through the valley of Fungching and the deep break in the higher plateau, west of Maanmiau, into the valley of the Té Hai, where its lofty terraces occupy the eastern part of this great depression.

The plain of the Kir Noor is formed by this deposit, which also extends through the valley on the east to the Si Ho tributary of the Yang Ho. As this formation

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[1] For results, mostly negative, of a microscopical examination of the loam of this deposit from different localities, see Nos. 1, 2, 3, 5, 7, 8, 12, in Mr. Arthur Mead Edwards' Letter, Appendix 3.

is found at the head of the water system of this northern branch of the Yang Ho, it must be continuous, unless washed away, in all the valleys of this basin between the plateau and the Barrier range. Thus the deposit in the valley of the Kir Noor probably continues, through the break in the plateau to the southeast, into the valley of the Si Ho, and through this to the Yang Ho. Indeed, judging from the appearance of the region lying between the plateau and the Barrier range, as seen from the tower at Ha Noor, this deposit seems to occupy here a large area.

We can trace some of the more important islands that were isolated by the lake in which this deposit originated. One of these seems to have been that part of the plateau lying between the Si Ho and the Kir Noor. Another instance is the low ridge that separates the Yang Ho from the Hwaingan creek, while a much larger one is the hilly country between the Yang Ho and Sankang Ho.

Thus the body of water in which this deposit was formed consisted of a series of lakes several hundred feet deep, occupying the valleys of the Sankang Ho, Yang Ho, and Si Ho, and standing at a level sufficiently high to cover the lower watersheds between these streams.

This deposit is everywhere a calcareous loam formed of an almost impalpable powder, easily crushed between the fingers, and yet so firm that vertical cliffs of it remain unbroken for many years, which is sufficiently proved by the fact, before stated, that the inhabitants of the country excavate entire villages in the base of perpendicular cliffs that rise more than 100 feet above their dwellings. When breaks occur, the loam falls in immense plates, or tabular masses, leaving a new vertical face. Near the mountain sides and in the narrow gorges the loam is more sandy, and contains the gravel and fragments of rocks coming from the immediate neighborhood, but everywhere else it consists uniformly of an almost impalpable powder.

A characteristic feature of this loam deposit is its tendency to cleave according to two vertical planes at right angles to each other, causing it to assume the form of needles under certain conditions of erosion.

The effects of erosion in this deposit are often very interesting, illustrating in a marked manner the retrograde formation of ravines. The country is often cut up by gullies 30 to 70 feet deep, and from 10 to 20 feet wide, with vertical walls. In these channels wagon roads run for many miles without rising to the plain. In the valley, between Kwantung (pu) and the Yangkau defile, I crossed a gully 40 or 50 feet deep, and not more than four feet wide, having the same breadth all the way down, and which, with these dimensions, follows a tortuous course for more than a mile. In the same valley another ravine of this kind, only eight or nine feet wide, and not less than 100 feet deep, compelled us to make a detour of over a mile.

Wherever a cliff of this deposit presents itself the beginning of this action is visible. The surface drainage of a small neighboring area of the plain being concentrated toward one point on the edge of the cliff, cuts, in its fall, a channel from top to bottom, and this, with each succeeding rain, works its way backward toward the mountains. As the erosion progresses the sides of the gullies offer new starting points for tributary ravines.

We have here, in the softest material that can support such action, a repetition

of the process which is causing the retrogression of Niagara falls, and which probably plays an important part in all valley erosion.

In intimate connection with this loam-deposit, stands the formation of the numerous isolated lakes met with on the route through the region we are now considering. I have frequently alluded to bars, or low watersheds, formed of the terrace-deposit, and stretching across valleys, causing the drainage to flow in opposite directions. These form the barriers to which almost every lake or pond, that has been mentioned, owed its existence after the retreat of the main body of the great inland sheet of fresh water.

We have seen that in those broad valleys where the lake-deposit has not been much subjected to erosion, its surface is not horizontal throughout, but rather, adapting itself to the general surface of the ground, or ancient valley, on which it lies, it rises from the centre to high on the sides of the surrounding mountains. Now when the sides of a valley approach each other and form a gorge connecting two broad enlargements of the valley, the terrace-deposit rises from the centres of both these basins, till it fills the gorge to about the same height as that at which it stands on the mountain sides around the basins. The height attained by the lake deposit in these narrow places is, in almost every instance, due to the fact that the usual deposit of loam was augmented by the large amount of detritus from the bordering hills.

As the large inland body of water disappeared and sank to the level of each of these bars, the sheet behind this remained isolated. In some instances the lakes thus formed have found outlets by cutting through their bars, but this was only where they received an important supply of water, derived from an extensive drainage area. In all other cases the barriers have suffered comparatively little from erosion.

Since their isolation these lakes have diminished in size, till they now possess but a small fraction of the volume necessary to fill their separate basins to a level with the surface of the inclosing bar.

I now propose to consider briefly the conclusions which the facts observed in this part of northern China seem to warrant.

The oldest stratified rocks seen throughout this region are highly metamorphosed and appear to belong to two distinct epochs; the hornblendic and chloritic series of schists representing the older, and the gneiss and granulite series, the younger.

After the deposition of the older metamorphic strata there seems to have been a disturbance producing folds with a trend between N. and W. Disturbances had also occurred by which the ridge between Nankau and Chatau was elevated and again depressed before the deposition of the great limestone formation, for the beds of this latter rest here immediately on the granite. Northwest of this ridge the limestone would seem to have been deposited in a shallower part of the sea, the character of the Hwaingan beds—which appear to represent the limestone—indicating the neighborhood of land.

After the deposition of the limestone strata these were traversed by the eruptive porphyries of Hiamaling, the debris of which form the chief ingredient of the conglomerate lying between the limestone and the coal-bearing series of Chaitang.

The next marked event was the forming of the coal-bearing rocks.

Although the disturbance, which was to produce the N. E. S. W. system of folds, appears to have been in operation before the deposition of the limestone, it was not until after the completion of the coal-bearing series, that this action cumulated in the great revolution by which the eastern portion of the continent received its outline, and the coal-bearing strata and older rocks were folded and prepared for the almost universal metamorphism that has affected them.[1]

An immense hiatus now occurs, for filling which there are no observed facts. This extends over the whole time that passed between the deposition of the coal-bearing rocks and the period of volcanic action in Southern Mongolia.

During this period occurred the eruption of the Kalgan trachytic porphyry and the deposition of its pluto-neptunian beds, and the outflowing on a gigantic scale, along the 41st parallel, of trachydoleritic and basaltic lavas.

The next phenomenon, of which the effects are visible, was the great dislocation by which at least the southern edge of the Mongolian plateau was raised. Near Fungching we have seen the high escarpment of the table-land, caused by this fault, trending away in a E. N. E. W. S. W. direction. If we produce this line toward the E. N. E. we shall find that it cuts the highest known point of the southern edge of the plateau—that near Ha Noor. The action of springs, that seem to rise along this fault line, is visible in the calcareous deposits seen near Maanmiau, and on the lower plateau near Fungching.

This great zone of volcanic action seems, as such, to mark the coast line of an extensive sea or ocean lying to the north, and it is an interesting fact that it lies nearly in a line with the axis of the Tienshan, in which we have every reason to believe that volcanoes still exist, though perhaps only as solfataras.

The dislocation by which the great escarpment of the plateau was formed, determined the depression between the table-land and the mountains south of it, which was to be occupied by the lakes already mentioned.

Before the deposition of the terrace deposit, the edge of the plateau had already been subjected to extensive erosion, by which great bays and channels were cut into it, and the valleys of the Té Hai and Kir Noor formed.

We come now to an interesting question—the origin of the chain of lakes so often referred to in the preceding pages, and of the deposit of loam by which they have recorded their former existence.[2]

That this deposit was formed in fresh water is shown by the presence of the shells found in the terrace of the Té Hai. The uniform character of the loam in the different basins, and in all parts of the same basin, its great extent, and the fineness of the material of which it consists, are conditions which prove that it is not of local origin, or derived from the detritus of the neighboring shores, but that it was brought into the lakes by one or more large rivers which must have drained an area of great extent. Now throughout the region in question, the only rivers are those of the Yang Ho and Sankang Ho basin, and, independently of the fact that these streams drain a very small area, the valley systems of these were almost entirely occupied by the lakes.

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[1] See Chap. VII.

[2] See Map XI, on Pl. 5.

Indeed the only direction from which a river of any importance could have come, was from the west, in which case it could only have been the Hwang Ho (Yellow river). Let us examine into the possibility of the existence of a communication between the valley of the Yellow river and the lake basins. When I was in the valley of the Té Hai, I saw distinctly that the break in the plateau continued to the W. S. W. as far as the eye could reach. A low, hilly country, much below the level of the plateau, appeared to shut in the valley at the distance of about twenty miles from the lake. Now on Klaproth's large map of Central Asia, on which, so far as my experience goes, the streams of this region are laid down with a remarkable approximation to accuracy, a branch of the Tourgen Gol[1] is given as rising in the very region occupied by the low hills observed by me. A native map of the province of Shansi, not always correct in its details, represents this stream as rising in the Té Hai.

Thus, I think, there is little doubt that a communication exists between the valley of the Té Hai and that of the Tourgen Gol, sufficiently depressed to be below the surface level of the terrace deposits. The Tourgen Gol is a tributary of the Yellow river, and if the watershed between the Té Hai and this river was below the level of the ancient lakes, these must have occupied part of the valley system of the north bend of the Yellow river, and must have left a corresponding deposit.

Now, although we have no information concerning the occurrence of the terrace deposit in the valley of the Tourgen Gol, we have direct testimony with regard to its existence over a large area in the land of the Ortous—the desert region inclosed by the northern bend of the Yellow river. Abbé Huc passed through this country on his way to Tibet, and describes it as a flat, sandy desert, frequently cut up by deep ravines, in the sides of which he observed, in one place, dwellings excavated in the same manner as those at Siwan.[2]

Indeed, all the information we possess concerning this region goes to show that it has been the basin of a great lake, which once extended from the northern bank of the Yellow river southwards to the mountains crowned by the Great Wall.[3]

Thus I think there can be little doubt that the terrace deposits, so common in the system of the Yang Ho, were precipitated in a chain of connected lakes, extending from Yenkingchau, N. N. W. of Peking, to near Ninghia (fu) in Kansuh, a

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[1] Haishui of the Chinese. The valley of Tourgen Gol is probably also connected with the valley of the Kir Noor; see p. 29.

[2] "When the Chinese establish themselves in Tartary, if they find mountains the earth of which is hard and solid, they excavate caverns in their sides. These habitations are cheaper than houses, and less exposed to the irregularities of the seasons. They are generally well laid out; on each side of the door there are windows giving sufficient light to the interior; the walls, the ceiling, the furnaces, the kang, everything inside is coated with plaster so firm and shining that it has the appearance of stucco. These caves have the advantage of being warm in winter and cool in summer. . . . . . These dwellings were no novelty to us, for they abound in our mission of Siwan. However, we had never seen any so well constructed as these of the Ortous."—Abbé Huc, Travels in Tartary, etc., Vol. I, p. 180.

[3] Compare Ritter's Erdkunde. Asien, especially Vol. I, p. 153—160; also Huc, Vol. I, p. 235; and Travels of Gerbillon, in Du Halde.

distance of nearly 500 miles; and that this sediment was brought by the Yellow river and the tributaries of its upper course.

We have seen that the immediate cause of the formation of these lake basins is probably to be sought in the dislocation forming the plateau wall to the north of them, the descent of the land previous to that event having probably been toward the Gobi, in which direction also the Yellow river flowed, if it existed at that time.

The waters of the Yellow river filled the chain of basins thus inclosed between the plateau and the mountains forming the southern wall. There are now two channels by which the drainage of all this area finds its way to the Yellow sea, the Yang Ho gorge in the far east which opens on to the great plain west of Peking, and the deeply cut channel through which the Yellow river flows between Shansi and Shensi. Whether both of these outlets existed during the lake period, or only one of them, is a question of much interest in a physical-geographical point of view, for if all, or part, of the waters of the Yellow river flowed through the Yang Ho gorge, they found their way to the sea through the lower Pei Ho, a stream with which the Yellow river has united within historical times, after having flowed in an entirely different course, viz. its present one, in part, to the west and south of Shansi.[1]

The Yellow river flows, from Pauteh (chau) to the mouth of the Wei river, nearly 300 miles, almost due south, traversing, in deep gorges, two important mountain ranges which seem to be great anticlinal ridges of the limestone, and several minor ones. Considering these things, the regularity of its course is striking when compared with the winding courses common to rivers that cross parallel ranges, and the inclosed longitudinal valleys. The thought is suggested that the course of this channel may have been determined by a great crack.

In connection with this subject, I will add that it is certainly remarkable that the Chinese traditions of two great floods, often cited in the west, toward proving the universal belief in a general deluge, all point to this region. The earliest of these traditions is allegorical and goes back to a time, about 3100 B. C., when the yet barbarous founders of the nation were still living west of Shansi. "Kingkung fought with Chwanchio for the empire of the world; in his rage he struck, with his horn, the mountain Puchiau, which supports the pillars of heaven, and the bands of the earth were torn asunder. The heavens fell to the northwest, and the earth received a great crack in the southeast."[2]

The other tradition, preserved in the Shuking of Confucius, refers to a later date, and partakes of a more historical character. According to this account,[3] there was a great flood in the 61st year of the reign of Yao (2297 B. C.); the waters of the Yellow river mingling with those of the Yangtse Kiang, and threatening to overflow the mountains. A skilful engineer, Pekuen, worked nine years, without success,

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[1] See Chap. V.

[2] Klaproth, Ritter's Asien, I, 158. Klaproth, in Asia Polyglotta, p. 28, comparing the dates of Hebrew, Brahminical, and Chinese traditions of deluges, obtains: Samaritan text, B. C. 3044, Brahminical date, B. C. 3101, Chinese, B. C. 3082.

[3] Ritter, Asien, I, p. 159. Compare Deguignes, Gesch. der Mongolen, Einleit. p. 4; and Mailla, Histoire générale de la Chine.

to effect a drainage; an object that was not accomplished until ten years afterward under the great Yu, by widening the channel of the river between Shansi and Shensi, especially in the gorges of Lungmun, Hukau, and Shanmun.

Mailla, one of the Jesuit missionaries employed in preparing the map of the empire, visited these localities, and relates that he saw with astonishment the remains of this gigantic enterprise.

However this may be, whether the works of Yu belong to the region of History or of Allegory, we have here two traditions, the first pointing to a convulsion causing a great flood, and perhaps also forming the channel between Shansi and Shensi; while the second evidently refers to an immense overflow of waters coming from the upper course of the Yellow river, and perhaps facilitated by obstructions in the narrow channel.

A gentleman, well versed in Chinese literature, informed me that, according to native authorities, the valley of the Yang Ho, between Chatau and Kiming, the easternmost of the ancient lake-basins, was once occupied by a lake which was drained, finally, by the Yang Ho gorge. Considering this, and the accounts of the Shuking, it is not, I think, impossible, that these traditions refer to the last events in the history of the lake period, and that within the memory of the Chinese people, a part at least of this great body of fresh water was still in existence, if, indeed, the formation of the channel between Shansi and Shensi, on which the retreat of the main body depended, does not also fall within this limit.

CHAPTER V.[1]

THE DELTA-PLAIN, AND THE HISTORICAL CHANGES IN THE COURSE OF THE YELLOW RIVER.

The extent of the great plain of Eastern China is pretty well known from native and Jesuit authorities. It lies in a semicircle around the mountainous peninsula of Shantung. Its outer limit, as approximately given on the Jesuit map, begins in the department of Yungping (fu), and, running west, keeps south of the Great Wall till Changping (chau) N. W. of Peking. Thence, remaining east of the southern branch of the Great Wall, it follows a general S. S. W. course, passing westward of Chingting (fu) and Kwangping (fu), till it reaches the upper waters of the Wei river. Here it turns westward into Hwaiking (fu), and crosses the Yellow river in that department.

From the right bank of this river it trends a little east of south, passing west of Jüning (fu) (Honan), and then turning eastward it continues south of Kwang (chau) and north of Luhngan (chau) in Luchau (fu). Here an arm of the plain, in which lies the Tsau lake, stretches southward from the Hwai river to the Yangtse, and continues eastward on the right side of this river, occupying the region between the river and Hangchau bay. A hilly region, in the centre of which is Nanking, rises, like a large island from the plain, to the north of this arm.

The Shantung boundary of the plain begins at Laichau (fu), and after describing a great bow to the south it turns west at Shukwang (hien), and running thence to Changtsing (hien), in Tsinan (fu), it turns to the south and around to the southeast. Keeping this course it remains nearly parallel to the Imperial canal till the Kiangsu frontier, which it follows to the sea.

The greater part of the area included within these limits is a plain which seems to descend very gently toward the sea, and to be very generally below the high water level of the Hwang Ho. It is the delta of the Hwang Ho, and in part also of the Yangtse Kiang, and is remarkable for its semi-annular shape, half inclosing, as it does, the mountain-mass of Shantung.

The city of Peking stands on a raised border of loam, sand, clay, and gravel, which forms the northwestern skirt of the delta-lowlands, and seems to extend southward fringing the mountains along its western side. The name of the Talo lake (Ta great, and lo plateau or raised plain) seems to refer to such a border, and

[1] See Maps I—X, on Plates 4 and 5.

in the article on Kichau in the Yukung it is said that "the Lo (plateau) was drained."[1]

The fact, also, that in historical times none of the arms of the Hwang Ho have approached the western mountain border of the plain, both north and south of Kaifung, within a less distance than from ten to fifty miles, seems to point to the existence of a recent sea margin, which would be perhaps due rather to the detritus brought down by local streams than to the delta deposit of the Hwang Ho.

All the important changes in the lower course of the Hwang Ho have been recorded from early times by Chinese historians, and their documents and maps form the most complete history we possess of the wanderings of any river.

The Yukungchuchi (Peking, 1705), written by Chin Hu Wei, contains a series of maps in which these changes are laid down for a period of more than 3000 years. M. Biot has given the substance of that part of this work that relates to the Hwang Ho, in a carefully prepared paper.[2] I have, however, thought the subject to be one of sufficient interest to warrant the reproduction of the maps of Chin Hu Wei, with such explanations as will render them intelligible, without going beyond the limits of a work that is intended to give only my own contributions to the physiography of Eastern Asia. For farther information I must refer the reader to M. Biot's paper, of which I shall make use in explaining the maps.

In the Yukung, a chapter of the Shuking classic of Confucius, it is said that the course of the Hwang Ho was regulated by the Great Yu. Whether the works of Yu are to be understood as the labor of a single man, or as the results of the enterprise of a rising colony during several generations, there seems to be little doubt that more than 2000 years before the beginning of the Christian era the Chinese had brought this turbulent river under their control, by an immense system of dykes, and had begun to cultivate the extensive marshes of the delta plain.

Map No. 1 of the series, on plate 4, represents the course of the Hwang Ho as it existed, in the main, from the time of Yu down to 602 B. C.

Map No. 2 represents the course resulting from the first great change, that of the fifth year of the reign of Ting Wang (Chow dynasty), 602 B. C.

Map No. 3 serves to illustrate a passage in the writings of the poet Sse Ma Tsien, recording a diversion to the east and southeast. The easterly course, forming the Pien river, seems to have been the earliest recorded tendency of the river to follow its recent course. The opening of the first channels in this direction is given as occurring in 361 and 340 B. C.

The diversion, indicated on this map, through lake Yungtse to the southwest, happened, according to Sse Ma Tsien, towards the end of the Chow dynasty, during the third century before Christ.

Map No. 4 represents changes that occurred under Wutih (Han dynasty), about 132 B. C., when a great overflow toward the northeast took place, the river trending toward Kai (chau) in Chihli. At this time several arms were formed between

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[1] E. Biot, Sur le chapitre Yukung, Journ. Asiatique, 1842.

[2] Sur les changements du cours inferieur du fleuve Jaune, Journ. Asiat. 1843.

Taming (fu) and the sea, which are also given. Previous to this, under Wentih, about 160 B. C., there was a breach formed at Yentsin near Kaifung.

Map No. 5 gives the second great change in the course of the "river of Yu," which occurred about 11 B. C., and was caused apparently by the blocking up of the channels leading to the Pei Ho.

Map No. 6 shows the channels as they existed during the Tang, and five succeeding dynasties, till the beginning of the Sung dynasty.

A note on the map of Chin Hu Wei says, "the course of the river remained the same from the time of Ming Ti (Tung Han dynasty) A. D. 70 . . . . . . till under Jin Tsung, A. D. 1034, when a break occurred at Hunglung, and another, fourteen years later, A. D. 1048, at Changwu, and the river of the Han and the Tang was entirely destroyed. The map covers a period of 977 years."

Map No. 7 (Pl. 5) represents the courses, under the Sung dynasty, from A. D. 1048 to A. D. 1194, a period of 146 years.

Map No. 8 records the course during the Kin dynasty. All the former channels appear blocked up, and the river, after entering Lake Lo, near the summit-level of the present Imperial canal, is seen to flow off to the N. E. through the Tatsing river, and to the S. E. through the Sz' river. Lake Lo appears from the observation of Clarke Abel, and from Chinese measurements, to be about 150 feet above the sea.

Map No. 9 shows the condition of the river under the Yuen and Ming dynasties, together with the Grand canal, a condition which seems to have remained substantially the same till within the last ten or fifteen years.

In early times the Yangtse entered the sea by three arms called the Sankiang, *i. e.*, "Three Rivers;" and Chin Hu Wei has given a map of these, founded on the opinions of early authorities. I have indicated them on map No. 1 of the series.

A glance at the nine maps of the delta courses will show how widely separated have been the limits of divergence of the arms of the Hwang Ho, within the past 3000 years. A mighty river, ever turbulent, subject yearly to an enormous increase in volume, an increase regulated rather by the amount of precipitation in the distant Kwenlun mountains, than by the local climate, it has ever been the terror of the countless millions through whose midst it flows.

From the earliest times an immense force has been at work to keep it from breaking through its dykes, or, when this has happened, to guide and retain it between new embankments. The quantity of solid material carried by the river and deposited along its course, is so great that its bed is rapidly raised, and appears to have been, before the last change, higher than the adjacent country.

Biot says, "it is certain that the bed of the river, from Hwaiking to the sea, is higher than the adjoining country."

Several times, during the great wars that have preceded the downfall of dynasties, this condition of the river has been turned to account as a weapon of offence. Breaking the embankments has been made to accomplish, almost instantaneously, by the destruction of hundreds of thousands of inhabitants, conquests that had been delayed by years of brave resistance.

From the earliest time of colonization on the delta-plain, the task of keeping the

Hwang Ho within its bed has been the constant care of the rulers of China, both when the country was united under one man, and when it has been subdivided into petty states. In the latter case in the treaties between states bordering on the Hwang Ho, the clauses regarding the regulation of that river appear to have been the most important and the most sacredly observed.

One of the most striking results of the official corruption that becomes general during the decay of a dynasty is the breaking loose of this great stream, as soon as the means for maintaining its embankments are misapplied.

The devastation caused by these overflows is awful beyond description. The loss of life is very great, and the destruction of the crops that form the means of support of millions, produces famine and the overrunning, by starving hordes, of the more fortunate districts of the adjacent country. The anarchy that rules in this struggle for life is almost beyond the conception of those who inhabit lands where the population is much below the capacity of the country, or which are easily reached by foreign supplies.

Within the last fifteen years one of these great changes has taken place, apparently from the same cause and with the same effect as above indicated. Instead of emptying into the Hwang Hai, or Yellow Sea, the Hwang Ho now has its mouth in the Gulf of Pechele, which it enters through the Tatsing river. The old mouth of the river was found to be dry in 1858.

According to information furnished to the Rev. Mr. Edkins, by officials of the Board of Foreign Affairs at Peking, the principal break occurred at Fungpeh (ting) in Süchau (fu), the waters flowing away to the N. E. In Tsinan (fu), the capital of Shantung, the waters of the Tatsing river are increased to six times their original volume by the contributions of the Hwang Ho.

In 1863 the river had not yet determined a channel, but its waters were spread over large tracts of country, and the city of Wuting (fu), nearly sixty miles north of Tsinan (fu), was almost inaccessible.

The present course of the Hwang Ho is indicated, so far as known, on Map No. 10.

Owing to the great quantity of material brought down by this river, and to the absence of great oceanic currents, that might, if present, interfere with its deposition, the delta is rapidly increasing in size, and the adjoining seas are becoming shallower.[1]

Probably nowhere can the rate of growth of deltas be better studied than in China. Cities that were built on the delta plain of the Hwang Ho several thousand years since are still in existence, together with the archives of their history. In the cases of those that were built near the sea, the distances from this are given; and frequent mention is made of towns, mounds, and natural hills, washed by the sea, within historical times, which are now far inland.

Thus, in B. C. 220, the town Putai is said to have been 1 li west of the sea-shore, while in A. D. 1730 it was 140 li inland,[2] a yearly increase of 100 feet, more or less,

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[1] Barrow estimated the hourly discharge of sediment at 2,000,000 cubic feet.

[2] Fangyuchiyau; Chihli.

according to the length of the li. Hienshuikau (on the Pei Ho, in long. 117° 32′ E.) is said to have been on the sea-shore in A. D. 500,[1] and is at present about eighteen miles distant, an increase of about 81 feet per annum.

Along the southern shore of the gulf of Pechele the yearly increase N. E. of Shukwang since B. C. 220, seems to have been not more than 30 feet.

The sea-shore, according to local tradition, was near the present location of Tientsin (fu) during the Han dynasty.

It is also recorded that under the reign of the Han, the Hwang Ho entered the sea at Changwu, near the present Tsinghai.[2]

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[1] Fangyuchiyau; Chihli.

[2] Ibid.

CHAPTER VI.[1]

ON THE GENERAL GEOLOGY OF CHINA PROPER; A GENERALIZATION BASED ON OBSERVATIONS, AND ON THE MINERAL PRODUCTIONS AND THE CONFIGURATION OF THE SURFACE.

It is with much misgiving that I begin even an attempt at a general sketch of the geology of China. The great extent of the country, the very limited area examined geologically, the, mostly, very general character of the observations made within that area, and our ignorance of the geological structure of the surrounding countries, render the attempt more than dangerous.

The sketch, and the map accompanying it, make no claims to accuracy, but I hope to show by means of them the leading features of the structure of the country, as deduced from observations in parts of the country and from mineral productions. The fact that hardly any two maps of China resemble each other in the geographical names; and that on most of them many of the names that I must use are not given, renders a sketch-map necessary, and this is to be regarded as a colored guide to the generalizations, and not as a geological map of the country.

The data on which the generalizations are founded consist in:—

My own observations.

The observations of other European travellers.

And in the information obtained from Chinese authorities.

The limits of my own observations have been already given; they were confined to the valley of the Yangtse Kiang, from the sea to near the eastern boundary of Sz'chuen, and to the northern departments of the provinces of Chihli and Shansi. The results of this portion of the data have been given in the preceding pages.

The observations of European travellers have furnished, so far as my knowledge of them goes, but very little information on the geology of the country, and even this is often vague and evidently incorrect. I have thought it worth while to give, in a condensed form, such information as I have been able to extract from this source.

Nanking to Canton.[2]—Gray, compact limestone is quarried back of Nanking. Siaukushan [Little Orphan Island], near the mouth of Poyang lake, is pudding-

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[1] See Map, Pl. 6.

[2] Clarke Abel. Narrative of a Journey in the Interior of China, and of a Voyage to and from the Country, 1816—1817, etc. Lond. 1818.

stone (?). The high Liushan [west of Poyang lake and south of Kiukiang] are of fine-grained granite and micaceous schist poor in quartz, in vertical strata trending N. E. S. W.[1] On the left bank of the Kan river, above Kihngan (fu), there is sandstone. Between Wanngan (hien) and Kanchau (fu) there is dark gray schist resting on granite. Black slate occurs between Kanchau (fu) and Nanngan (fu). The summit of the Meiling pass is of argillaceous sandstone, immediately south of which begins limestone. Between Nanhiung (fu) and Shauchau (fu) the limestone ceases and is followed by red sandstone with coal seams. Nearer to Shauchau (fu) there is limestone resting on a breccia of limestone, calcareous red sandstone, and quartz, the whole cemented by limestone. Near Yingting (hien) there is grayish-black limestone in which is the cavern of Kwangsin. Hills of grayish-yellow, argillaceous sandstone, with veins of quartz, occur about half way between Yingting (hien) and Hingyuen (hien); [on Abel's route map the whole country between these two places is represented as sandstone.] The coal brought to Abel from the towns on the Yangtse resembled cannel coal, that in Kiangsi "bovey" coal.

At Fuhutang (on the Kan river), soon after leaving the Poyang lake, there are vertical coal pits. The fragments at the bottom of the hill where these are situated appeared to be pure slate.[2]

Canton to Hankau through Hunan.[3]—The rocks noticed on the North river (Peh kiang) were red sandstone and limestone. Four miles inland from Pangkwang there are coal mines, belonging to the government, 40 to 50 feet deep. Red sandstone occurs along the boundary between Kwangtung and Hunan on the Meiling pass. Red sandstone occurs near Shachulung, a coal village on the north slope of the Nanling near the end of the Meiling pass. A few miles below Laiyang (hien) there are limestone quarries. At Pingtan, a few miles below Siangtan (hien), there are limekilns and quarries of limestone. Sandstone is quarried at Kingtsewan, about twelve miles below Changsha (fu).

Chehkiang and Fuhkien.[4]—About ten to fifteen miles west of Yenchau (fu) (Chehkiang) are limestone mountains, and a few miles farther west beautiful green granite. Near Hwuichau (fu) (Nganhwui) the hills consist of a red sandstone resting on slate. Near Küchau (fu) (Chehkiang) there is red, calcareous sandstone. The road on the pass between the Shangyang river and the Chehkiang river is paved with granite. The road at the N. W. foot of the Bohea mountains leading from Hokau, in Kwangsin (fu) (Kiangsi), into Fuhkien, is paved with granite. The rocks at Wuishan, on the east side of the Bohea mountains in Fuhkien "consist of clay slate, in which occur, embedded in the form of beds or dykes, quartz rock, while granite of a deep black color, owing to the mica which is of a fine deep bluish black, cuts through them in all directions." "Resting on this clay slate are sandstone conglomerates formed principally of angular masses of quartz, held together by a calcareous basis, and alternating with these conglomerates there is a fine, calcareous,

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[1] Ritter, Asien, III, p. 675, citing Ellis' Journal, p. 342, and Clarke Abel, p. 167.

[2] Ellis' Journal, II, p. 107.

[3] Rev. Mr. Bonny. A Trip from Canton to Shanghai. Pamphlet. Shanghai, 1861.

[4] Fortune. Tea Districts, etc.

granular sandstone in which beds of dolomitic limestone occur." "Granite forms the summits of most of the principal mountains in this part of the country."

Canton to the Sea.[1]—A gray-wacke, containing much quartz, forms the hills near Canton. Underneath this rock is red sandstone, "varying from a bright red, fine-grained rock to a coarse conglomerate, full of large pebbles of quartz." These strata dip to westward. Granite occurs below the sandstone and crops out more and more, as the river approaches the sea. Near the coast the granite forms peaks 1,200 to 2,000 feet high, which continue as barren islets toward the island of Hainan.

Kingyuen (fu) in Kwangsi.[2]—The marble mountains south of Kingyuen (fu) give rise to innumerable large springs, and even rivers disappear in them to come again to light after following long subterranean courses. The many colored varieties of marble of this region are celebrated, and the marble formation (Marmor Gebirge) seems to predominate.

Salt Wells of Sz'chuen.[3]—M. Imbert has given a vivid description of these, and although it has often been quoted, it is sufficiently interesting to be inserted here.[4] These are at Wutung, in the department of Kiating (fu), and near the city Kiating.

"There are some ten thousand of these springs, or artificial brinepits, in a space about ten leagues long and four or five leagues broad. The Chinese effect the boring of these pits with time and extreme patience; yet with less expense than with us. They have not the art of working rocks by mining (blasting?); yet all the pits are constructed in the rock. These pits are commonly from 1,500 to 1,800 feet (French) deep, and are only five or at the most six inches in diameter. These little wells, or tubes, are perpendicular, and as polished as glass. Sometimes the entire depth is not continued in solid rock, but the workmen encounter beds of shale, coal, etc.; then the operation becomes more difficult, and sometimes fruitless; for as these substances do not offer a uniform resistance, it sometimes occurs that the shafts lose their perpendicularity; but these are rare cases. When the rock is favorable, they advance at the rate of two feet in the twenty-four hours. It requires at least three years to sink one pit." A pit of this kind costs about 1,000 taels of silver.[5] "The mode of pumping is exceedingly simple, yet laborious; being effected chiefly by manual labor. The water is very briny, giving, by evaporation, a fifth or more, and sometimes one-fourth, of salt."

"The air, which escapes from these pits, is very inflammable. If a torch is presented to the mouth of the shaft, the gas ignites, with a great column of fire, from twenty to thirty feet in height, exploding with the rapidity of powder." This gas is conducted through bamboo tubes to the saltpans under which it is burned to effect the evaporation. "Sometimes, in boring the salt pits, very thick beds of coal are passed through at a depth of several hundred feet." "In sinking these wells a bituminous oil [petroleum], which burns in water, is commonly found at a depth of about 1,000 feet. They collect daily four or five jars of 100 pounds each. This

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[1] Chinese Repository, III, p. 87.

[2] Ritter, Asien, III, 758.

[3] Imbert, Annales de l'association pour la propagation de la foi. Vol. III, p. 369.

[4] The extract given here is taken from R. C. Taylor, Statistics of Coal, Phil. 1848, p. 660, with some remarks from Chinese Repository, XIX, p. 325.

[5] 1 Tael = $1.33.

oil has a very powerful odor, and is used to light the area where the pits and coppers of salt are concentrated."

"The largest fire wells are those at Tsélieoutsing, forty leagues from Wutung. Tsélieoutsing, situated in the mountains, on the banks of a small river, also contains salt pits, bored in the same manner as at Wutung. In one valley are seen four pits which give a flame, to an amount truly frightful, but no water. These pits, for the most part, have previously afforded salt water; which water being drained, the proprietors, twelve years since, caused them to be sunk even to *three thousand feet and more* of depth, hoping to procure an abundant supply of water. All this was in vain; but there suddenly gushed forth an enormous column of air which brought with it large, dark particles. These did not resemble smoke, but the vapor of a glowing furnace. This air escaped with a roaring and frightful rumbling, which was heard at a great distance. The orifices of the pits are surmounted by a wall of stone six or seven feet high, for fear that, inadvertently, or through malice, some one might apply fire to the opening of the shaft. This misfortune happened in August last. As soon as the fire was applied to the surface of the well, it made a frightful explosion, and even something was felt approaching to an earthquake. The flame, which was about two feet high, leaped over the surface of the earth without burning anything. Four men devoted themselves and carried an enormous stone over the orifice of the pit. Immediately it was thrown up into the air; three of the men were scorched, the fourth escaped; neither water nor dirt would extinguish the fire. Finally, after fifteen days of stubborn work, a quantity of water was brought over the neighboring mountain, a lake or dam was formed, and the water was suddenly let loose, which extinguished the fire. This was at an expense of about thirty thousand francs."[1]

Fossils from China.[2]—Mr. Davidson, after examining a collection of shells sent by Dr. Lockhart to the British Museum, came to the conclusion, "that the specimens belonged to eight Devonian species, seven of which are common to several European localities, among which we may mention Ferques and Néhon (France), Belgium, and the Eifel, but they are not found all existing together in any one of these localities. In external aspect they most resemble those from Ferques, in which locality, however, neither the *Cyrtia Murchisoniana* nor the *Rhynchonella Hanburii* have been as yet discovered." If to these we add the other two described by M. de Koninck,[3] the total number of Chinese Devonian types now known will amount to ten species: viz., 3 of Spirifer, 2 of Rhynchonella, 1 Productus, 1 Crania, 1 Cornulites, 1 Spirorbis, and 1 Aulopora. The species determined by Mr. Davidson were as follows: Spirifer disjunctus, *Sowerby;* Cyrtia Murchisoniana, *De Koninck;* Rhynchonella Hanburii, *Davidson;* Productus subaculeatus, *Murchison;* Crania obsoleta, *Goldfuss;* Spirorbis omphalodes, *Goldfuss (?);* Cornulites epithonia, *Goldfuss (?);*

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[1] Compare Humboldt, Asie Centrale, II, p. 521, 525.

[2] On some Fossil Brachiopodes, etc. T. Davidson. Quart. Journ. Geolog. Soc., IX, 1853, p. 353.

[3] "Notice sur deux espèces Brachiopodes du Terrain Paléozoique de la Chine." Bullétin de l'Académie Roy. des Sciences, Lettres et Beaux Arts de Belgique. 1846. XIII, pt. 2, p. 415.

Aulopora tubaeformis, *Goldfuss;* Spirifer Chechiel, *De Koninck;* Rhynchonella Yuenamensis, *De Koninck.*

Some fossil brachiopods from Gouchouc, twenty leagues W. S. W. from Patang on the Kinsha Kiang, and near the Tibet-Sz'chuen frontier, were determined by M. Guyerdet[1] as follows: Terebratula cuboides, *Sow*, carb. and Devon., figured in Descript. des Anim. foss. de la Belgique, De Koninck, 1842—1844, p. 285. Terebratula reticularis, *Linné*, Devonian; figured in Russia and the Ural mountains: Murchison and v. Keyserling, II, 90. Terebratula pugnus, *Martin;* figured in Sowerby, Conchyl. pl. ccccxcvii. Mr. Woodward has described an Orthoceras from China.[2]

Hoshan (*Fire Mountains*).—These are without doubt burning seams of coal. One of these burning mountains, called Hoyau, occurs 55 li N. W. of Kwangling in Tatung (fu), Shansi.[3]

Sir R. I. Murchison speaks of some Upper Devonian fossils, from Sz'chuen, given to him by Dr. W. Lockhart, as "identical in specific character with Spirifer Verneuilii, S. Archiaci, Productus subaculeatus, and other European forms."[4]

I was told by the Rev. Mr. Edkins that the island of Situngting in the Taihu lake (west of Shanghai) contains fossiliferous limestone.

In the following table are given a large number of localities of coal and alum (the latter is made in China, I believe, always from pyritiferous shales that accompany coal), to be used in locating the coal-bearing formation; and of indications of limestone, as limestone-marbles, limestone, caves, stalactites, fossil brachiopods, etc. These localities are in every instance, unless otherwise stated, taken from Chinese geographical works, especially from the Tatsingytungchi, and the geographies of the separate provinces.

This is followed by a table of salt wells in Yunnan and Sz'chuen, which will be explained further on; and by a table of gold-bearing localities to assist in locating the granito-metamorphic formation.

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1 Comtes Rendus. Acad. des Sciences, Paris, 1864, LVIII, No. 19, p. 878.

2 Quart. Journ. Geol. Soc., 1856, p. 379.

3 Biot, in Journ. Asiat., 1840, October.

4 Siluria, p. 425. Lond. 1859.

TABLE OF LOCALITIES OF COAL, ALUM, LIMESTONE, LIMESTONE-MARBLES, FOSSILS, CAVES, STALACTITES, ETC., IN CHINA.[1]

F = fu ; C = chau ; H = hien.

Province.	Department.	District.	Place and circumstances of occurrence.
Chihli.	Shuntien F.	Fangshan H.	Anthracite, S. W. 40 li at Hwanglung Mt., white marble.
	" "	Wangping H.	Anthracite at Muntakau, Maanshan, and Tatsau.
	" "	" "	Bituminous at Chaitang and Chingshui.
	" "	Waitso H.	White marble.
	Yungping F.	Funing H.	70 li N. E. at Liulu Mt., coal. At Shïling, coal.
	Kwangping F.	Tsz C.	Coal.
	Siuenhwa F.	- - - - -	Coal at Kingtingpu.
	" "	Yü C.	Anthracite (Shïtan).
	" "	Paungan C.	Anthracite (Shïtan). Coal in hills north of Sin-paungan.
	" "	" "	Anthracite at Kiming.
	" "	Sining H.	Anthracite (Shïtan).
	" "	Wantsuen H.	Anthracite (Shïtan). 15 li S. brown coal at Wu-taiyau.
	" "	- - - - -	Brown coal 60 li N. N. W. of Kalgan at Wushïkia.
	" "	- - - - -	Coal at Siautungko 180 li W. of Kalgan.
	Pauting F.	Y. C.	Great cavern in Mt. Lungchi. (B.)
	Chingting F.	- - - - -	Several large caverns.
	Shunteh F.	- - - - -	Several large caverns.
Shansi.	Taiyuen F.	Chauyang H.	Large caverns near Chauyang H. 100 li E. of Taiyuen F. (B.)
	" "	- - - - -	Large caverns near Tseuhong. (B.)
	" "	- - - - -	Coal 12 miles S. W. of Taiyuen on W. side of Făn R. (Bagl.)
	" "	- - - - -	Coal 35 miles S. W. of Taiyuen on W. side of Făn R. (Bagl.)
	" "	- - - - -	Lime burnt, 30 miles S. W. of Taiyuen on W. side of Făn R. (Bagl.)
	Pingting C.	Soyang H.	Anthracite (Shïtan).—Alum.
	" "	- - - - -	Coal 12 W. of Pingting C. (Bagl.)
	Hin C.	Tsingloh H.	Anthracite (Shïtan).
	Tatung F.	- - - - -	Bituminous coal "quarried" in large blocks (Ta-tan) near the city.
	" "	Kwangling H.	Coal.
	" "	Lingkiu H.	Stalactites in Mt. Peshan.
	Fănchau F.	- - - - -	Coal and lime 17 miles S. of city in the range east of Făn R. (Bagl.)
	" "	Ling H.	Coal 70 li E.
	Pingyang F.	Yching H.	Anthracite (Shïtan).
	" "	Yoyang H.	Anthracite (Shïtan).
	" "	Lingfung H.	Anthracite (Shïtan) near Pingyang.
	" "	Hungtung H.	Anthracite (Shïtan).
	" "	Fehshan H.	Anthracite (Shïtan).
	" "	Taning H.	Great caverns 20 li N. W. in Mt. Kung.
	" "	Kih C.	Lime.—Alum.
	Hoh C.	Lingshï H.	Anthracite (Shïtan).
	Tsehchau F.	Yangching H.	Anthracite (Shïtan).
	Kiang C.	Yuenchü H.	Alum.
	Kiai C.	- - - - -	Alum.
	" "	Ngany H.	"Cave of the Winds" S
Shensi.	Yulin F.	Yulin H.	Anthracite (Shïtan) 20 li S. E. at Mt. Tan.
	Tungchau F.	Chingching H.	Alum.
	" "	Tungkwei H.	Alum.
	Fungtsiang F.	Kienyang H.	Cavern, 30 li S. E.
	Ningkiang C.	- - - - -	Fossil Brachiopods (Shïyen).

[1] B. = Biot; Bagl. = Rev. P. Bagley; Edk. = Rev. Mr. Edkins.

TABLE OF LOCALITIES OF COAL, ALUM, LIMESTONE, LIMESTONE-MARBLES, &c.—*Continued.*

Province.	Department.	District.	Place and circumstances of occurrence.
Shensi.	Hanchung F.	- - - - -	Fossil Brachiopods (Shïyen).—Many large caverns. (B.)
	Yenngan F.	Yenchuen H.	Petroleum springs.
	Tungchau F.	- - - - -	Coal 15 miles above junction of Făn R. and Hwang Ho. (Bagl.) Many caverns in the Tsepe, Lungmun, Taney, and Seou mountains. (B.)
Kansuh.	Lanchau F.	- - - - -	Coal 40 li S. W.
	" "	Titau C.	Coal 80 li distant.
	" "	Kin H.	Coal 40 li N. W.
	Kungchang F.	Tungwei H.	Coal 60 li S. E. at Lieutungping.
	Tsin C.	Tsinngan H.	Coal 10 li N. W. at Sulungpu.
	Ninghia F.	- - - - -	Coal N. E. on opposite bank of Hwang Ho (Huc).
	Liangchau F.	Yungchang H.	Anthracite (Shïtan) 20 li S. E. at Mt. Tan.
Jehho.	Chingteh F.	- - - - -	"Bad coal" 40 li S. E. at Mangninchuenkau.
	" "	- - - - -	Anthracite, E. near Sankia, W. of Palisade.
	" "	- - - - -	Anthracite and bituminous coal 40 li E. of Sankia.
	" "	- - - - -	Much coal among the mountains along the Palisade.
Shingking.	- - - - -	Kaiping H.	Anthracite.
	- - - - -	- - - - -	Coal on W. coast of Liautung promontory in lat. 39° 40′.
	- - - - -	- - - - -	Coal S. E. of mouth of Liau R.
	- - - - -	Chauyang H.	Coal at Latsz Mt.
Shantung.	Tsingchau F.	Yihte H.	Coal and alum at Yehchintsung.
	Taingan F.	- - - - -	Stalactites.
	Ichau F.	Kü C.	Stalactites, 150 li N. at Yünkungshan.
	Tsinan F.	- - - - -	Much coal in the range, 33 miles E. (Bagl.)
Kiangsuh.	Kiangning F.	- - - - -	Coal at Chunhwachen half-way between Kin-yang H. and Nanking. (Edk.)
	" "	Kiangpu H.	Great cave ("Pit of Heaven") 30 li W.
	Chinkiang F.	Kintang H.	Stalactites 65 li W. at Mt. Mau.
	Süchau F.	Siau H.	Anthracite and lime 30 li S. E. at Peitutsung on Mt. Peitu.
	Süchau F.	- - - - -	Marble on islands of Taihu lake.
Nganhwui.	Ningkwoh F.	In all the H.	Anthracite (Shïtan).
	Taiping F.	Fanchang H.	Brown coal? (Kaufung.)
	Ho C.	Heishan H.	Coal.
	Luchau F.	Tsau H.	Large cavern near town.
	" "	Luhkiang H.	Alum.
	Fungyang F.	- - - - -	Alum.
Honan.	Honan F.	Kung H.	Coal.
	" "	Loyang H.	Coal.
	" "	Tungfung H.	Stalactites in Mt. Sansz.
	Ju C.	Lusan H.	Coal.
Hupeh.	Ichang F.	Kwei C.	Coal on banks of Yangtsekiang.
	" "	Patung H.	Coal on banks of Yangtsekiang.
	Yunyang F.	Fang H.	Stalactites.—Alum.
	Kingchau F.	Changyang H.	Cavern in Mt. Fang.
Sz'chuen.	Süchau F.	- - - - -	Coal on Yangtsekiang near the city. Coal at Lotu.
	Kiating F.	Kienwei H.	Coal in the salt district. (Imbert.)
	" "	- - - - -	24 caves in a mountain near the salt wells.
	Chungking F.	- - - - -	Coal.
	Chung C.	- - - - -	White marble 70 li N. W. at Mt. Peishï.
	Tungchuen F.	Pungchi H.	Limestone 90 li S. E.
Chehkiang.	Hangchau F.	In all the H.	Limestone in all the mountains of the department.
	" "	- - - - -	Many caverns in Mt. Pelaifung.
	" "	Changhwa H.	Fossil Brachiopods (Shïyen) in Shïyen cave at Mt. Yunko.
	Huchau F.	- - - - -	Coal.—Stalactites in Wanglung cavern.
	Wanchau F	Pingyang H.	Alum.

TABLE OF LOCALITIES OF COAL, ALUM, LIMESTONE, LIMESTONE-MARBLES, &c.—*Continued.*

Province.	Department.	District.	Place and circumstances of occurrence.
Chehkiang.	Chuchau F.	- - - - -	Caverns in many of the mountains.
	" "	Lungtsiuen H.	Fossil Brachiopods and a cavern on Mt. Wangmatsien.
	Shauhing F.	- - - - -	Caverns.
	Taichau F.	- - - - -	White marble on Mt. Tsang.
	Kinhwa F.	Kinhwa H.	Cavern (Tsutsesantung).
	" "	Lanki H.	White stalactites at Peiyün cave in Mt. Tungnien.
	" "	" "	Lime at Peikang Mt.
	Yenchau F.	Tsenngan H.	Stalactites.
	" "	Tunglu H.	Stalactites at Langsien cave.
	" "	Fănshui H.	Cavern (Yangsantung).
	Küchau F.	Singan H.	Coal.
	" "	Kiangshan H.	Coal (Chin. Rep. xix, 387).
	" "	Changshan H.	Coal (Chin. Rep. xix, 387).
Kiangsi.	Nanchang F.	Fungsin H.	Anthracite at Lauhukau.
	Yuenchau F.	Pinghiang H.	Anthracite.
	" "	Făni H.	Cavern and Fossil Brachiopods.
	" "	Wantsui H.	Fossil Brachiopods.
	Kwangsin F.	- - - - -	Coal (Chin. Rep. xix, 387).
	" "	Tsienshan H.	Alum.
	Linkiang F.	Sinyü H.	Stalactites.
Hunan.	Changsha F.	Liuyang H.	Alum.
	Hăngchau F.	Hăngshan H.	Coal. Fossil Brachiopods at Mt. Nesho.
	" "	Laiyang H.	Coal.
	" "	In all the H.	Alum.
	Pauking F.	Siying H.	Coal.
	Kweiyang C.	- - - - -	Fossil Brachiopods at Mt. Shïyen.
	" "	In all the H.	Alum.
	Yungchau F.	Lingling H.	Fossil Brachiopods.
	Changteh F.	Nganhiang H.	Fossil Brachiopods.
Kweichau.	Chinyuen F.	- - - - -	White marble just east of the city.
	Shihtsien F.	- - - - -	"Dragon Cavern" 1 mile S. W. of city.
Yunnan.	Wuting C.	Yuenmau H.	Alum. Caves with bones. Fossil Brachiopods in the Kauhyin Mt.
	Yungchang F.	- - - - -	Caverns.
	Yauking? F.	- - - - -	Caverns. (B)
	Tali F.	- - - - -	Orthoceratites.
Fuhkien.	Hinghwa F.	- - - - -	Coal (Chin. Rep. xvi, p. 80).
	- - - - -	Anko	Anthracite (Chin. Rep. xvi, p. 80).
	Changchau F.	- - - - -	Caverns.
	Funing F.	- - - - -	Caverns.
	Tsiuenchau F.	- - - - -	Caverns.
Kwangtung.	Shauchau F.	- - - - -	Coal.
	" "	Juyuen H.	Stalactites.
	Shauking F.	- - - - -	Stalactites and Fossil Brachiopods at Mt. Shïyen.
	" "	- - - - -	Dendritic marble.
	Lienchau F.	- - - - -	Stalactites.
Kwangsi.	Kingyuen F.	- - - - -	Ossiferous caverns in the Nanshan Mts.
	Kweilin F.	- - - - -	Fossil Brachiopods.—Stalactites.
	Pingloh F.	Pingloh H.	Stalactites 31 li E
	" "	Kungching H.	Stalactites 5 li E. at Mt. Kintsumi, and 28 li E. at Mt. Yintieh.
	" "	Lipu H.	Stalactites 1 li S. at Mt. Sung.
	Wuchau F.	Tsinki H.	White marble 10 li N. at Peishï.
	" "	Hwaitsih H.	Marble 80 li S. W.
	Yulin C.	Pohpeh H.	Stalactites 30 li S.
	Sinchau F.	Pingnan H.	Fossil Brachiopods 12 li S. E. at Mt Yenshï.
	Nanning F.	Suenhwa H.	Fossil Brachiopods 90 li E. at Mt. Shïyen.
	Taiping F.	Shangsz C.	Stalactites and white marble 2 li E. at Mt. Peishï.

TABLE OF LOCALITIES PRODUCING SALT FROM ARTESIAN WELLS.

Province.	Department.	District.	Place and circumstances of occurrence.
Sz'chuen.	Chingtu F.	- - - - -	Wells.
	" "	Kien C.	Wells.
	Tsz C.	- - - - -	80 wells.
	" "	Tszyang H.	4 wells.
	" "	Nekiang H.	2 wells.
	" "	Jinshan H.	10 wells.
	" "	Tsingnien H.	237 wells.
	Ningyuen F.	Hwuili C.	Wells.
	" "	Yenyuen H.	Wells.
	Pauning F.	Langtsung H.	Wells.
	" "	Nanpu H.	Wells.
	Shunking F.	In all the H.	Wells.
	Süchau F.	Fushun H.	Wells.
	Chungking F.	Pah H.	Wells.
	" "	Pihshan H.	Wells.
	Chung C.	- - - - -	Wells.
	Kweichau F.	Wan H.	Wells.
	" "	Wushan H.	Wells.
	" "	Yunyang H.	Wells.
	" "	Fungtsi H.	Wells.
	" "	Kai H.	Wells.
	Suiting F.	Tatsoh H.	Wells.
	Tungchuen F.	In all the H.	Wells.
	Mei C.	Pangshan H.	Wells.
	Kiating F.	Weiyuen H.	Wells.
	" "	Yung H.	Wells.
	" "	Ticwei H.	Wells.
	" "	Lohshan H.	Wells.
	Kung C.	Puhkiang H.	Wells.
	Lu C.	Kiangngan H.	11 wells N. W. of town
Yunnan.	Yunnan F.	Nganning C.	80 wells.
	Tali F.	Yunglung C.	Wells.
	" "	Langkiung H.	Wells.
	Tsuhiung F.	Tingyuen H.	Wells of black salt.
	" "	Kwantung H.	Wells of black salt.
	" "	Yau C.	Wells.
	Wuting C.	Tsauchitsing.	Wells.
	" "	Yuenmo H.	Well at Tsukiutsing.
	Likiang F.	- - - - -	Wells at Sipeh Mt.
	Pu'rh F.	Ningurh H.	Red salt.
	Kingtung (Ting)	- - - - -	Wells.
	Yungpeh (Ting)	- - - - -	Wells.
Shensi.	Kia C.	- - - - -	Lake salt.
	Yulin F.	Yulin H.	Lake salt 80 li S. at Yühopu.
	" "	Tingpien H.	Salt lake N. W. at Yentsangpu ("salt mine").
Shansi.	Taiyuen F.	Taiyuen H.	Salt.
	" "	Tsingyuen H.	Salt.
	Hin C.	Tingsiang H.	Salt.
	Kiai C.	Ngani H.	Salt lake.
	Tatung F.	Tatung H.	Salt.
	" "	Hwanyuen C.	Salt.
	" "	Ying C.	"Excellent salt at Yanghochiao."
	Lungan F.	- - - - -	Salt.
	Pauteh C.	- - - - -	Salt.
	Hoh C.	- - - - -	Salt.
	Sieh C.	- - - - -	Salt.

TABLE OF GOLD WASHINGS AND MINES.

Province.	Department.	District.	Place and circumstances of occurrence.
Chihli.	Shuntien F.[1]	Miyun H.	Gold mine 8 li E. of city.
	Yungping F.	Tsienngan H.	Gold washings in the Kwaihochuen R.
	" "	Lulung H.	On Mt. Tsu.
Shensi.	Singan F.	Lintung H.	On Li Mt. 2 li W. of city.
	Shang C.	Lohngan H.	Coarse wash gold at Hwanglungshan 80 li N. E. of city; and rich washings at Yanghwashan.
	Hanchung F.	Sihiang H.	Gold.
	Hinngan F.	Hanying (ting)	Coarse gold in the Han R.
Kansuh.	Lanchau F.	------	Coarse wash gold.
	Kungchang F.	Min C.	Coarse wash gold.
	Kiai C.	Wăn H.	Coarse wash gold.
	Sining F.	Sining H.	Coarse wash gold.
	Suh C.	------	Gold 70 li W. of the city at Tungtingshan.
	Chinsi.[2]	------	Gold 60 li E. at Kinshan.
Shantung.	Ichau F.	Lanshan H.	Gold and silver mine 90 li S. W. at Paushan, and gold 60 li N.
	" "	Kü C.	Gold 100 li N. at Chipaushan.
	Tsingchau F.	Linkü H.	Gold-sand 60 li S. W. at Sungshan.
	Tungchau F.	------	Gold.
Hupeh.	Hwangchau F.	Hwangkang H.	Wash gold 140 li N. at Tankingshan.
	" "	Hwangan H.	Gold E. at Tsangkiashan.
	Kingchau F.	------	Gold.
	Shinan F.	Kienchi H.	Coarse wash gold 15 li W. at Shïjoushan.
Sz'chuen.	Chingtu F.	Kien C.	Coarse wash gold.
	" "	Wangkiang H.	Coarse wash gold.
	" "	Tsungking H.	Coarse wash gold.
	" "	Pang H.	Coarse wash gold.
	Mien C.	------	Coarse wash gold.
	" "	Ngan H.	Nugget gold N. E. at Kinshan.
	Ningyuen F.	Yenyuen H.	Gold 30 li W. at Hokinhoshan, and very coarse gold 150 li N. W.
	Pauning F.	Kwangyuen H.	Coarse wash gold.
	" "	Pa C.	Coarse wash gold.
	" "	Kien C.	Coarse wash gold.
	Chungking F.	Yungtsang H.	Gold washings.
	" "	Hoh C.	Gold washings.
	" "	Fuh C.	Gold washings.
	Yuyang C.	Pangshui H.	Coarse wash gold.
	Chung C.	------	Coarse wash gold.
	Kweichau F.	Wan H.	Coarse wash gold 3 li S.
	Suiting F.	Tatsoh H.	Gold.
	Lungngan F.	Pingwu H.	Coarse wash gold.
	Mei C.	------	Coarse wash gold.
	Lu C.	------	Coarse wash gold in the Tsungkiang R.
	Ya C.	------	Coarse wash gold in the Fihkiashui R.
	Mau C.	------	Gold.
Chehkiang.	Ningpo F.	------	Gold at Kehyüshan.
	Yenchau F.	In all the H.	Wash gold.
	Chuchau F.	Lungtsiuen H.	Light-colored gold.
	-----	Sungyang H.	Light-colored gold.
Fuhkien.	Taiwan F.	Fungshan H.	Gold E. at Kinshan.
	Fuhchau F.	------	Coarse gold.
Kiangsi.	Nanchang F.	Fungsin H.	Gold-sand.
	Jauchau F.	Poyang H.	Gold at Hwangkingtseh.
	Fuchau F.	Lingtse H.	Gold 40 li W.
	Kanchau F.	Shuikin H.	Gold.

[1] Peking.

[2] Barkoul.

TABLE OF GOLD WASHINGS AND MINES.—*Continued.*

Province.	Department.	District.	Place and circumstances of occurrence.
Kwangtung.	Shauchau F.	Yingte H.	Gold.
	Hwuichau F	Hoyuen H.	Gold at Lantienta.
	Shauking F.	Kaikien H.	Gold at Kintsung.
	" "	Kwangning H.	Gold at Kinkung.
Hunan.	Changsha F.	------	Gold.
	Hängchau F.	------	Gold.
	Yuenchau F.	------	Gold.
	Changteh F.	------	Gold.
	Chin C.	------	Gold.
	Tsing C.	------	Gold.
	Yochau F.	------	Gold.
Kwangsi.	Liuchau F.	Yung H.	Gold.
	" "	Laiping H.	Gold.
	Sz'ngan F.	Pin C.	Gold.
	" "	Tsienkiang H.	Gold.
	" "	Shangling H.	Gold.
	Pingloh F.	Pingloh H.	Gold.
	" "	Yungngan C.	Gold.
	Wuchau F.	Hwaitsih H.	Wash gold in river at Kinngohshan 70 li W.
	Sinchau F.	Kwei H.	Gold.
	Nanning F.	Hwang C.	Gold mines.
Kweichau.	Tungjin F.	------	Gold-sand washings 100 li W. in the Sung'chi R., and 140 li W. in the Tichi R.
	Tsuni F.	Tungtsz H.	Gold.
Yunnan.	Tsuhhiung F.	Yau C.	Coarse gold in the upper Tayauho R.
	" "	Tsuhhiung H.	Gold in the Yenshan.
	Likiang F.	------	Gold washed in many places in the Kinshakiang for a distance of 500 li.
	Yungchang F.	------	Gold mines in the Changpangshan.
	" "	------	Gold washings in the Lantsan R.
	Tungchuen F.	------	Gold washings in the Kinshakiang.
	Yungpeh (Ting)	------	Gold.

Before attempting to sketch the distribution of the known formations of the Chinese empire, I will give the principal reasons for assuming a general simplicity in the geological structure of that country; for believing that the surface of the Eighteen Provinces is made up almost exclusively of the following formations: the Granito-metamorphic,[1] the Devonian limestone, the Triassic, Coal measures, and the younger Tertiary and Post-tertiary deposits.

Wherever the rocks beneath the Devonian limestone were seen, in central and in northern China, these were found to be either metamorphic schists, or granitoid rocks, with the one exception of a thin bed of sandstone, already mentioned as underlying the limestone at the entrance to the Lukan gorge of the Yangtse. At the Meiling pass, on the northern boundary of Kwangtung, the limestone is said to rest on granite.

An exception to this rule exists, perhaps, along the coast range in southeastern China, where the valley of the Canton river is said to expose an extensive formation of "graywacke" resting on granite.

[1] By the Granito-metamorphic formation is here meant the stratified and non-stratified rocks of different ages, older than the Devonian limestone.

The Sinian, or N. E. S. W. system of elevation corresponds in many respects to our Appalachian system, and if the analogy holds good throughout, it seems probable that the Sinian revolution terminated soon after the deposition of the Chinese Coal measures, a supposition that is corroborated by the absence, so far as my observation goes, of any younger formations elevated by this revolution.

The apparently total absence, in the line of the Yangtse, of eruptive porphyries, greenstones, trachytes, and basalts, seems to point to a corresponding absence of subsequent disturbance through a large area of the country.

Again, were there fossiliferous strata of the Jurassic or Cretaceous ages, their petrifactions would be found in all parts of the empire, used as curiosities and as medicines, as is the case with the fossil brachiopods and orthoceratites. This is important evidence in China, where art is based on the remarkable, or rather strange, in nature.[1]

In classifying the above tabulated data, I have assumed that the gold washings are indicative of the neighborhood of the granito-metamorphic formation, and have referred this to the adjacent ridges. I have also assumed that the limestone marble, lime, caves, stalactites, and fossil brachiopods, etc., all point to the presence in each locality of the same great bed of Devonian limestone. My own observations in the northern provinces and along the Yangtse, those of Blackiston in Sz'chuen, and the remarks of casual travellers in the south, all point to one, and only one, great limestone formation, which everywhere underlies the coal-bearing rocks, and to which, in all probability, all the indications above given refer.

That the brachiopods belong to this formation is merely an inference, for I never was able to find a fossil of any kind in the limestone. It is, however, an inference based on circumstantial evidence, as when they are frequently cited as occurring in caverns or in the same neighborhood with marble, or stalactites, etc., or in close proximity to coal localities.

With regard to the coal-bearing rocks, I have supposed the coals to belong to the same age throughout the empire, excepting a few which seem, from their names, to be tertiary brown coals. The similar character of the fossils, from the north and from the Yangtse, and the position of given localities with reference to the limestone in many parts of the country, favor the assumption.

Had we good topographical maps of China, the sketch I am about to attempt would be much facilitated; but although the water-courses are laid down on the Jesuit map, with a general approximation to accuracy that is very remarkable, we have very little knowledge of the orography. In the first pages of this paper I pointed out the prevalence of the northeast, southwest direction in the prominent features of Eastern Asia, and went so far as to apply this rule to the establishing

[1] Both the Chinese and Japanese have a strong taste for the *bizarre* in nature, as shown by their fondness for dwarfed or deformed trees. Waterworn and cavernous rocks are carried long distances to be used in ornamenting gardens, and quarries are worked for blocks of dendritic limestone to be made into articles of furniture or ornament. All kinds of fossils are esteemed as medicines, and sold as such in all apothecary shops, the brachiopods as Shïyen "stone swallows," and the fossil bones and teeth, from caverns and loam deposits, as "dragon's teeth," "dragon's scales," "dragon's bones," etc.

of several principal anticlinal axes of elevation in China Proper. In this sketch I shall endeavor to give more reasons for the locating of these ridges, which, on the small, general sketch-map, are represented by the limestone and granite streaks.

In describing the structure of the northern part of Chihli and Shansi, a range was often mentioned under the name of the Barrier range. Its trend is here west of S. W., and its prolongation would cross the Hwang Ho in Pauteh (chau), and thence run S. W. through Shensi and Kansuh, coinciding with the watershed between the eastern and western reaches of the great bend of the Hwang Ho. We have already seen that this range has elevated the Devonian limestone in its northeastern part. The Hwang Ho traverses it through an immense gorge, a fact which in China is almost proof of the presence of the limestone. West of this range are the coal localities of the Ninghia (Fu) and Lanchau (Fu).

The next great axis, to the eastward, seems to originate, like the former, in the mountain-knot of the Ourangdaban, near the Tushi gate of the Great Wall, N. W. from Peking. Following a S. W. course it forms the range which we crossed at the Nankau pass, and crossing the Shansi boundary it is known as the sacred Wutaishan. Still further to the S. W. it crosses the Hwang Ho under the name of the Lungmun shan [mountains of the Dragon gate]. In northern Chihli we have seen that this is a granite range flanked with the Devonian limestone; the latter formation is indicated to the S. W. in the lime works west of the Făn river, in the caverns of Taning H. and the lime of Kih C., in the celebrated Lungmun gorge, through which the Hwang Ho passes this range and in the caverns of Fungtsiang F. I have supposed its continuation bordering on the highlands of western Sz'chuen, forming the watershed between the Sz'chuen and Tibetan sources of the Yangtse.

Between these two apparently principal axes there seem to be minor ones, but I have colored the intervening space as Coal measures. In it lie the coal basins of Siuenhwa F. in Chihli; of Tatung F. and Tsingloh H. in Shansi; and of Yulin F. and Pingliang F. in Shensi.

We come now to the central axis of elevation, to which attention was called in the beginning of this paper, and the establishing of which was there based on a study of the map. Where this range crosses the Yangtse, we have seen that it consists of two anticlinal ridges of limestone with an aggregate breadth of 80 miles, and containing between them a coal basin. In its continuation S. W. to the Nanling mountains it seems to occupy a large part of Kweichau. The only data for this portion of the range are, the numerous gold washings at the base of the watershed between Kweichau and Hunan, that I have taken as indications of the granito-metamorphic formation, and the caverns and marble localities of Shihtsien F. and Chinyuen F. In its continuation to the N. E. it is crossed by the river Han, and gives rise to the sources of the Hwai river. It disappears at the edge of the great delta plain to rise again as the watershed of Shantung. In this province the numerous gold localities that stretch through the centre from S. W. to N. E. indicate the presence of the older metamorphic rocks, which, indeed, according to my own observation, form the coast near Chifu. The stalactites of Taingan F. and Kü C. are the only data for coloring in the limestone. The continuation of this range further to the N. E. is found in the limestone islands that stretch from Shantung to

the "Regent's Sword," and thence through Liautung, as the Changpeh shan, dividing the waters of the Yaluh and of the Usuri from those of the Liau and the Sungari. In passing close under the precipitous shores of Liautung, I observed that this promontory is made up of parallel N. E. S. W. ridges, and the rocks had all the appearance of limestone.

Between this central axis and that previously described, lies, perhaps, the most important fold of the Coal measures. Beginning in the extreme north, we find coal at several localities along the west coast of Liautung, and along the "Palisade" west of the Liau river. In northern Chihli are the coal basins of Yungping F., of Peking, and of Kwanping F.; in Shansi those of Pingting C., Taiyuen F., Fănchau F., Hoh C., Pingyang F., Tsehchau F., and Kiang C.; in Honan those of Honan F. This main fold, or zone of folds, seems to occupy a large part of the provinces of Sz'chuen and Yunnan. Many minor ridges bring the limestone to the surface in these provinces. In this region almost all the indications of the Coal measures, exclusive of the information given by Capt. Blackiston, refer to the great salt deposits. The following considerations have led me to look upon these deposits as members of the Chinese Coal measures. Some, at least, are in the neighborhood of abundant coal mines.[1] Thick coal seams are sometimes bored through before reaching the salt. They occur at various points along the Yangtse as in Wushan H., Chingking F., and Süchau F., in all which places they must be very near ridges of limestone, but above that formation. In Shunking F. and in Kiating F., they are also near such ridges. If the wells are in rocks younger than the limestone, their depth (500 to 2,600 feet) cannot penetrate to anything older than the limestone. This, and the fact that thick seams of coal are bored through in these wells, and the remark of Blackiston that all the coal rocks he saw in Sz'chuen resembled those of the Kwei coal field, the character of which we know, render it, I think, probable that both the coal and the salt deposits belong to the Chinese Coal measures.

The region in question, though containing many small parallel troughs, seems to be, as a whole, a major trough, if I may use the expression, between two principal anticlinal axes, and, as such, it seems to be traceable through Eastern Asia. To it the S. W. N. E. course of the Yangtse in Sz'chuen owes its direction, and the same may be said of the northern part of the delta plain, the Gulf of Pechele, the valley of the Liau river, and that of the lower Amur, and the depression in which lies the Gulf of Penjinsk.

On the sketch map the two members of the central anticlinal axis, which we have seen to exist where it crosses the Yangtse, are represented as continuing separately in Honan and Kweichau. Whether the course of the Wu river, in the latter province, is sufficient indication of a continuation of the synclinal trough of Kwei toward the S. W. is doubtful, but to the N. E. the coal basins of Ju C. in Honan, and of Yihte H. (Tsingchau F.) in Shantung fall in that line.

East of this central axis is another major trough or basin. In this are some of the coal basins of Hunan, the lake-plain of the Tungting, and the valleys of the

[1] Imbert, in Annales de l'Assoc. pour la propag. de la Foi.

rivers Yuen and Tsz, all in Hunan, and in Nganhwui the valley of the Hwai, and the coal basin of Süchau in Kiangsuh.

This trough is limited on the east by what would seem to be a band of parallel ridges extending from the province of Kwangsi to Kiangsuh. We have seen the Yangtse crossing one of these between Hankau and Kiukiang, while another, broken through by the Poyang lake, shuts in the valley of the Yangtse on the east. The river flows between these two from the Poyang to beyond Nanking.

Numerous indications of the limestone as stalactitic caves, fossil brachiopods, etc., extend in a southwest direction through Kiangsi and Hunan into Kwangsi, while in the same belt are many evidences of the Coal measures.

That the space between these ridges is occupied by coal basins in part of Kiangsi and Nganhwui is certain, and here belong also the coal basins of southeastern Hunan. I have, therefore, represented them as independent throughout. In the easternmost of these, east of the Poyang lake, are the granite hills of Kingteh, which furnish the celebrated kaolin[1] for fine porcelain, while Abel mentions granite and micaceous schists as occurring in the high hills west of the lake in the western ridge.

The data for the next trough to the east are the existence of what seem to be shales and sandstones of the Coal measures on the Kan river from Nanchang F. to the Meiling pass, and the coal fields of Kwangsin F. (Kiangsi), of Küchau F. and Chuchau F. (Chehkiang), of Ningkwo F. (Nganhwui), in every *hien* of which there is coal, and of Huchau F. (Chehkiang).

We come now to the coast axis of elevation marked by the range of mountains that separate Nganhwui and Kiangsi from Chehkiang and Fuhkien.

We know that at the Meiling it is of granite flanked with limestone; the fact that Mr. Fortune found the peaks near the headwaters of the Min river to be granitic, and in the northeast the granitic islands of Chusan, all indicate a granite range, while the table furnishes numerous evidences of the presence, on both sides, of the great limestone formation.

There are even fewer data for understanding the structure of the eastern and southern provinces than for almost any other part of the empire. Scattered indications of limestone and coal, and the courses of some of the rivers have prompted me to insert another axis of elevation, nearer the coast and stretching from Hongkong to Wanchau F. in Chehkiang. Such an axis is apparent in the granite[2] islands that stretch away toward Hainan, and to it this island seems to belong.

The indications of the Coal measures along the coast are the coal fields of Hinghwa F. and Nganki H.[3] (Tsiuenchau F.).

The prolongation of the coast axis of elevation cuts the southern and most mountainous parts of Corea, and coincides nearly with the granite axis of Kamschatka.

I have thus far in this sketch made no mention of any other system of elevation than the N. E. S.W.; but, as we have seen in a former chapter, another system, the

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[1] This word is said to be derived fron *kao*, high, and *ling*, ridge.

[2] Chin. Repository.

[3] This I take to be the *Anko* mentioned in the Chin. Rep. as producing anthracite.

E. W., exists, and to its disturbing influence are due some of the most important and beneficial features in the structure of the country.

Between the Wei river of Shensi and the Sz'chuen boundary, two ranges, parallel branches of the prolonged Kwenlun, with a general trend from west to east, penetrate far into Central China. Some of the peaks of these chains are said by Klaproth, on Chinese authority, to rise above the snowline. The numerous gold localities in this region point to an extensive development of the older metamorphic rocks, while the presence of stalactitic caves and other indications of limestone seem to show that this formation flanks the ranges in question.

The trends of the upper courses of the rivers Han and Kialung, and the communication said to exist between these streams at Ningkiang C. seem to indicate that the space between these ridges is an elevated table-land, divided by a low watershed that separates the sources of the Han from those of the Kialung. This watershed would be in the line of the limestone range represented as crossing Shansi, Shensi, and Western Sz'chuen.

The disturbances caused by the northernmost of these ridges ceases in Honan, but the southern member seems to continue farther east, apparently crossing Hupeh into Nganhwui.

Of the mountains in Southern China that belong to this system, we know as little as of those just mentioned. They are spoken of as containing snow-capped peaks and high table-lands in Kwangsi and Kweichau, and are supposed by Humboldt[1] to be the continuation of the Himalaya mountains. The hydrography of Yunnan, as shown on the great map of Kanghi, would seem to indicate the existence of a more or less elevated plateau, which, beginning west of the Lantsan river, trends nearly east, entirely across Yunnan, occupying a region in which rise tributaries both of the Yangtse and the Si Ho, and of the rivers that flow to the Gulf of Tonquin. The little that is known of the climate of the city of Yunnan F. (in about 25° N.) tends to confirm the supposition that it is on an elevated table-land.[2] This plateau seems to extend to the western part of the province, where it appears to terminate abruptly toward the plain of the Irawaddi river, for Marco Polo required two days and a half to descend from the city of Yungchang F. to the lowlands of Ava, and speaks of the descent as being very great ("grandissima discesa.")[3]

Toward the east these highlands are represented by Klaproth as forming two diverging ranges of mountains, the northernmost of which is crowned with snowy peaks and glaciers till near the head waters of the Yuen river.[4] There seems to be little doubt that in the meridian of Kweilin F., and to the east of that point, this northern branch forms a comparatively low range, and is nearly lost in the N. E. S. W. system.

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[1] Asie Centrale. [2] Ritter, Asien, III, 754. [3] Ritter, Asien, III, p. 746.

[4] Ritter, Asien, III, p. 660. Klaproth, Mag. Asiat., II, pp. 139, 156.

CHAPTER VII.[1]

THE SINIAN[2] SYSTEM OF ELEVATION.

I HAVE taken the liberty of giving this name to that extensive N. E. S. W. system of upheaval which is traceable through nearly all Eastern Asia, and to which this portion of the continent owes its most salient features.

We have seen how generally prevalent this trend is in China, whether we consider the hydrography, the courses of the mountains,[3] or the strike of the strata.

In crossing the plateau of Mongolia from the Great Wall to Siberia, I found the same trend predominating in the uplifted strata of old metamorphic rocks, and generally in the ridges that cross the steppes of the Gobi.

A glance at any recent map of Siberia will show that the same rule may be applied to all of the eastern part of this vast region. The Yablonoi, Altan-kingan, and Stanovoi mountains, with all their intermediate, parallel ridges, that together form the valley network of the upper Lena and Amur rivers, are instances of the development of this system on a grand scale. Although exceptions—that may or may not belong to this system—to the general N. E. trend seem to exist in the Great Kingan mountains—the eastern edge of the great plateau—and in the continuation of the Stanovoi in the far northeast, still to the configuration arising from the prevalence of this trend, are due the most marked features of Eastern Asia. The seas of Ochotsk and of Japan, the gulfs of Pechele and of Tonquin, are geoclinal valleys of this system of great geological age, which the disturbances of a long range of time have not been able to obliterate. And a similar valley is, I think, indicated for the land by the line of reference I have drawn through the valleys of the Yangtse and Amur. As throughout China and across Mongolia I was unable to find anything more recent than the Chinese Coal measures affected by this uplift, and as, to the extent of my knowledge, no younger rocks are affected by it in Siberia,[4] it seems proper for the present to refer all the N. E. ridges to one system, and their origin to one revolution.

The, in many places, unconformable strikes and dips of the older metamorphic schists of China show the existence of disturbances that had ceased before the formation of the great bed of limestone.

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[1] See Map, Pl. 7.

[2] From Sinim, the name applied to China in the earliest mention made of that country.—Isaiah.

[3] That the general trend of their mountains is N. E. was known to the early native writers.

[4] The explorations of M. Tchihatcheff, in the Altai, the eastern part of which belongs to the system in question, failed to discover any rocks more recent than the Permian, affected by this uplift.

The Sinian revolution seems to have begun after the deposition of the limestone, and before that of the Coal measures; at least the difference in character that is visible between the beds that overlie the limestone on the two flanks of the anticlinal ridge in Western Hupeh, and the presence, at the bottom of the Coal measures near Peking, of conglomerates, formed from porphyries that are younger than the limestone, are facts that seem to favor this idea. It is not improbable that these first movements determined the outlines of the principal areas of land and water, and of the future coal basins. The revolution does not seem to have reached its climax till after the Coal measures had been deposited, when the strata were plicated and prepared for metamorphism.

Very striking analogies are apparent between the Sinians and our own Appalachians. Both have the same trend; both are the results of revolutions, which, though they may not have been coextensive in time, were contemporaneous through a long period; and both have folded immense areas of coal-bearing strata. As the elevation of the Appalachians determined the outline of Eastern America, so the Sinian revolution fixed the eastern boundary of the great continent.

We have, in this analogy, one more link in the chain of evidence toward proving the subordination to harmonious laws of the causes that have produced all the varied features in the configuration of our planet.

One of the most remarkable features in the configuration of the northern hemisphere, seems to me to be the number of geoclinal valleys having a nearly N. E. S. W. course, that characterize it. In the extreme east of the great continent we find one, occupied by the sea, between the Japanese Islands and the coast range of Manchuria; between this and the Kingan mountains[1] another, which I have several times alluded to as the principal line of reference in treating of the Sinian features; the Gobi, including the region between the Kingan and the Altai, forms a third. These troughs have all been referred to in the preceding pages, but, if I may be permitted to generalize beyond the closer limits of this paper, I think a much larger one exists in the vast extent of lowlands that stretch unbroken, excepting by the Ural mountains, from the Altai to the Scandinavian peninsula.

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[1] The eastern edge of the plateau, unlike the southern, is formed by parallel ridges trending between N. E. and N. by E., the valleys between which form succeeding terraces from the plateau to the Sungari river. Prince Krapotkin, who travelled in disguise from the Argun river to Mergen, ascending the Gan river, and descending the Noumin river, gave me the following information: The ascent to the edge of the plateau from the west was hardly perceptible, the descent to the east rapid. In descending he crossed four parallel ranges trending N. N. E., all of which are traversed by the tributaries of the Sungari. The specimens brought back by Prince Krapotkin, chiefly from the ranges, were mostly granite, porphyries, argillaceous and micaceous schists, and gneiss. Coal is abundant along the eastern slope.

According to M. Radde the mean height of the Amur between the Kingan mountains and the Bureja mountains, is 800 feet above the sea; between Mochada and the Kur river, from 400 to 500 feet.—*Radde, in Petermann's Mittheilungen*, 1861, pp. 449—457.

MM. Saurin and Murray, of the English Legation in Peking, informed me that in ascending to the plateau from the region west of Jehol, they followed a valley through a mountainous district, and reached the table-land without seeing any signs of an abrupt wall, such as it presents along its southern edge.

Through this broad tract two minor valleys are indicated, one in the trough that contains the Aralo-Caspian depression and the lakes of the Barabinsky steppe, and the other containing the Kara sea, the White sea, the lakes of Finland and the Baltic.

Beyond the mountains of Norway the great depression occupied by the Sea of Greenland and the North Atlantic, is one of the best defined in this series of valleys.

Finally, in the vast extent of lowlands of British America we have a great geoclinal depression lying between the Appalachians and the Rocky mountains, forming an elevated geoclinal valley between N. E. and N. W. systems of elevation; just as in the North Pacific Ocean we have a depressed valley of the same kind between N. W. and N. E. systems—the Rocky mountains and the Sinians.

Both Prof. Guyot and Prof. Dana have demonstrated the fact that the principal continental outlines are referable to N. E. and N. W. systems of trends.

CHAPTER VIII.[1]

GEOLOGICAL SKETCH OF THE ROUTE FROM THE GREAT WALL TO THE SIBERIAN FRONTIER.

The route, here described, after following for about 100 miles that along which the measurements of MM. Fuss and v. Bunge were made, leaves this and remains about 60 miles to the west of it for most of the distance, joining it again in about latitude 47° N.

The journey was made in the months of November and December, the thermometer ranging from +15° to —28° F., with an almost incessant, strong, northwest wind. This, and the fact that we travelled seventeen hours a day, will, I think, be a sufficient excuse for the meagreness of the information. Nothing but the absence of all geological observations over this immense region, prompts the insertion of the following scanty notes.

Nov. 21, 1864. Leaving Kalgan we ascended to the plateau by the Tutinza road.[2] For the first two or three days the intensely cold winds made it impossible to take notes. The great volcanic formation, which we have seen forming the southern edge of the table-land for a long distance to the westward, extends from thirty to fifty miles in this direction, as the only rock in place, and the conformation of the surface is similar to that with which we have become acquainted in describing the journey to the west, only the valleys are generally broader and more shallow.

During the next fifty miles our route crossed several low ridges, chiefly granitic, the intervening plains being covered with the detritus of quartz and metamorphic sandstone. This is succeeded by a rolling country with hills of red granite, diorite, and greenstone porphyry, which continues to beyond the low granite ridge of Mt. Ugundui.[3] The fragments on the surface of the plains were mostly of granite and quartzitic sandstone, together with scattered pieces of lava and pebbles of chalcedony, agate, etc.

Nov. 26. After passing Mt. Ugundui the character of the country underwent a marked change. Our road lay, from the last-named mountain to the Mingan hills, through a depression. In the distance the flat outline of the plateau was seen on all sides, the intervening country being cut up into isolated knobs and ridges by numerous water-courses and lake beds. The structure of the knobs shows them to

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[1] See Section on Pl. 7.

[2] This portion of the road, as far as the summit of the plateau, was described in a previous chapter.

[3] Many of the names of places, etc , used in this sketch are given on Klaproth's large map of Central Asia.

be the remnants of a deposit the horizontal beds of which were continuous over the area in question. I examined one of these hillocks, about 50 feet high, near lake Bilika Noor, and found it made up of the following beds, from younger to older:—

Compact, yellowish-gray limestone, with a tendency to oolitic structure.

Thin bed of dark clay, or earth, with concretions of manganese.

Bed of finely crystalline, white, saccharoid gypsum.

Gypsum in massive, transparent crystals associated with more or less red clay.

The stratification is horizontal throughout, and the same structure seemed to be continuous as far as the Mingan hills. What the character of the plateau is I could not determine; as seen in the distance it limits the depression with a cliff and long talus.

An alluvial deposit of red loam is present in many of the valleys, and is, perhaps, nearly contemporaneous with the erosion of the water-courses.

Nov. 27. In the morning we found ourselves in the Mingan hills, apparently an isolated protuberance rising only a few hundred feet above the plateau. The rocks of these hills, where first observed near the southern edge, were chiefly quartzite, compact sandstone, and a talco-argillaceous schist, in highly inclined strata trending N. W. and dipping to N. E. Several miles further to the northwest we came to ridges of limestone, in beds also highly inclined, with a strike W. N. W. and dip to S. S. W. This rock resembles the limestone of the hills west of Peking. It is traversed by dykes of greenstone. In the Mingan hills I found a few rolled fragments of basaltic lava similar to that of the southern edge of the plateau.

To the west of these hills lies the broad deep valley of Olannoor, which seems to connect the depression south of these hills with the great plain of Tamchintala, to which we now descend. As we enter upon this steppe we see before us nothing but an unbroken sandy and gravelly plain with a little scattered grass. A considerable percentage of the pebbles on the surface consists of agate, cornelian, and chalcedony.

Nov. 28. The morning found us still travelling on the Tamchintala, but we soon descended into a large valley-like depression. The plateau is here cut into to the depth of perhaps 150 feet, the vertical wall giving an insight into its local structure. The whole exposed thickness consists of horizontal strata of white calcareous sandstone with thin beds of arenaceous limestone interstratified. At the bottom of the section a bed of red arenaceous clay crops out. The sandstone varies in grain from a fine grit to a fine conglomerate, the ingredients of both being apparently identical with those of the gravel on the surface, between which and the underlying rock there is no line of demarcation. If the pebbles of agate, cornelian and chalcedony are derived from the amygdaloidal lava, so common farther south, their occurrence in this deposit throws light on the relative ages of the two formations.

After crossing this valley depression, which is several miles broad, we ascended to the plain at about the same level, apparently, as on the other side.

Nov. 29. During the previous night we left the plain and entered a rough and very undulating country. Here a belt of older rocks, about seventy miles broad,

seems to rise a little above the general level of the plateau. Its position is marked on most maps by the boundary line between inner and outer Mongolia.

As we entered these hills during the night I could not see the structure of their southern edge, but where first observed, several miles from that point, the outcropping rock is a compact hard sandstone, in nearly vertical strata trending about E. W. Beyond this the next rock observed was granite in red and white varieties, traversed by numerous dykes of brown porphyry with bright red crystals of feldspar.

The surface of this granite region forms numerous depressions, the bottoms of which seem to be occupied, in the wet season, by ponds without outlets. In the gravel of one of these depressions I found a slightly rounded fragment of silicified wood.[1]

Nov. 30. The morning of this day found us still in the hilly region. The rocks along the road were clay schist. We came, early in the morning, to a narrow gravelly plain, which, descending between two granite cliffs, opened out on to the broad plain of the valley of Ulannoor.

The hills on either side of the narrow plain just mentioned, which are of coarse granite traversed by a similar rock of finer grain, are bare, without either soil or vegetation, excepting two or three dwarf trees growing from crevices in the rock. These trees were the only ones seen on the plateau between Kalgan and the hills of Urga.

Entering the valley of Ulannoor near Gashun we found ourselves in a country of high terraces, these consisting, where seen, mostly of beds of clay. This clay would seem to be the equivalent of the calcareous sandstone, and is covered, in the narrow valley mentioned above, by a deposit of loam.

Crossing the valley of Ulannoor, we entered a valley in the hills of Ulandzabuk-daban. Here the ground was covered with angular fragments of clay-slate, and gneiss.

Rolled fragments of porous lava were also found on the surface.

Dec. 1. This day our road lay through the hills of Senji, which consist of alternating vertical strata of micaceous, argillaceous, and talcose schists, and compact limestone in blue, black, and white varieties, all having a very regular trend to about N. E. These strata are traversed in all directions by dykes of greenstone. Large lenticular masses of quartz were also observed, and some broad veins of the same material, apparently interstratified, and discolored with the oxides of iron and manganese.

The frequent repetition of the more easily recognizable rocks would seem to show a highly folded condition of the strata.

The limestone having better resisted the action of disintegration, forms ridges from 100 to 150 feet high above the bottoms of the troughs formed by the removal of the intervening softer rocks. Thus the general appearance of the surface is that of parallel valleys and ridges. But here too we find the same tendency to form depressions without outlets, that we have already seen in the granite region (Nov. 29th), and

[1] Silicified wood was shown to me in Peking under the name of Hanhaishï. Hanhai is the Chinese name for the Gobi desert.

which is mentioned in a previous chapter as occurring along the southern edge of the plateau, in the erosion of the lava region. In all these instances the depressions are entirely in the solid rock, and vary in size from a few yards to several thousand feet across. They have the appearance of being produced by erosion and not by sinking. In the instance before us this conformation is often assisted by cross dykes of greenstone. But the occurrence generally would seem to arise from inequalities in the texture of the rock. Whatever the cause of these depressions may be, their manner of formation is probably closely connected with the origin of a large class of desert lake beds.

For many miles the surface of the rock was entirely bare of soil, excepting in the bottoms of the depressions just mentioned, where ponds are probably formed in wet years.

From this hilly region we came gradually into another of those broad plains, which form, in the aggregate, the true plateau. These plains, the steppes of the Russians, and *tala* of the Mongols, are like those of our own deserts in the Rocky mountains. They are great valleys, often from twenty to sixty miles broad, filled with marine deposits that have retained their horizontal position and remained often intact from erosion. Their surface is not, strictly speaking, horizontal, but slopes from both sides to the centre.

The deposit forming the substructure of this plain, seems to be the same sandstone and conglomerate that we have seen on the Tamchintala, judging from some blocks of these rocks seen near a Mongol dwelling.

Crossing this plain we came, near its northern edge, to a line of basaltic cones from 100 to 150 feet high, isolated from the low flat hills to the north, and apparently resting on clay slate. They seemed thus to belong to a bed or stream rather than to a dyke. Whether the flat hills near by are a continuation of the same volcanic rock I could not determine.

The rock is a brownish-black, minutely crystalline basalt. On the surface of the plain, near these hills, I found large numbers of fragments of black and red cellular lava, and abundant angular pieces of chalcedony, and red and green jasper, etc.

Dec. 2. During this day we crossed two broad valley depressions, the same calcareous sandstone and conglomerate already mentioned, forming apparently the substructure both of the long valley slopes and of the higher land intervening between these. A few fragments of blue limestone and white quartz, derived probably from the formation we crossed yesterday, were found in the surface gravel; but a large percentage of this gravel consisted of chalcedony, cornelian, and agate.

From the highest ground the flat outline of the plateau was visible in every direction, excepting to the south, where we could see the hills of the past two or three days rising to the height of perhaps 1000 feet above the neighboring plateau.

Dec. 3. We travelled the past night and this day on the continuation of the steppes of the last two days. During the afternoon the plain descended gradually to the north till it ceased abruptly against a granite ridge from 50 to 100 feet high. Beyond this ridge, for a few miles, the country though somewhat lower than the plain of the morning, is bare of the steppe deposit, and presents a rough, granite surface.

Dec. 4. Detained one day by a *bouran* or snow-storm of great violence.

Dec. 5. Travelled over a rolling country chiefly of granite and mica schist. Associated with the latter rock is a white dolomitic limestone in apparently interstratified beds, impregnated with specks and flakes of graphite. The general trend of these rocks appeared to be to the N. W.

The granite had, in places, more the appearance of a metamorphosed conglomerate breccia than of a true granite.

In the afternoon we encamped among outcrops of trachytic porphyry identical in character with that of Kalgan. I found here all the kinds seen at Kalgan, including a striped variety, and specimens with primary quartz. This porphyry contains veins and concretions of chalcedony and cornelian.

Dec. 6. Our road lay all day over a rolling country, granitic and syenitic rocks prevailing, till in the evening we reached the foot of a picturesque granite peak, the Bogdo oola,[1] rising several hundred feet above the surrounding country. To the west of this we saw a large valley with water or, rather, ice.

An accident detained us here till the next afternoon.

Dec. 7. Started in the afternoon, and after passing the Lamasery of Churinchelu, and travelling a few miles along the foot of the Bogdo oola, encamped for the night.

Dec. 8. Travelled about 20 miles over a rough country. As the ground was covered with snow, I saw but little of its character, the outcrops seen being all granitic.

Dec. 9. This day we were again on the undulating country of the plateau and the great steppe deposit. Near our camping place were many fragments of volcanic scoriæ and of chalcedony.

Dec. 10. Our road was still on the steppe of yesterday, the surface rising rapidly toward the north. The rolled detritus on the surface was mostly derived from mica-schist, and clay slates, and in a ravine I observed the former rock in place. Near this we entered the hills that limit the steppe, and found them to be of basalt, at least as far as the camping place.

Dec. 11. This day found us in the range of hills that, trending S. W. from the Kentei mountains, forms the watershed between the steppes of the Gobi and the valleys of the Tula and Orkhon rivers, whose waters flow to the Arctic Ocean.

The country is here made up of rounded, grassy hills, of about the same height, with valleys remarkable for the regularity of their long, unbroken, cross curves. The hills are of a black, metamorphosed clay schist, and a compact, greenish rock, chiefly feldspar and quartz, apparently a metamorphic greenstone. The strike of the clay rock, where observed, was N. S., and the dip vertical.

The valley bottoms, and the lower slopes of the hills, are covered with a rich, black earth, the deposit showing no signs of erosion. Our camp this night was in the Horteryndaban.

Dec. 12. During at least the greater part of the past night we were descending, and daylight found us in a valley much like that which leads from Kalgan to the plateau, viz., a narrow, gravelly descending plain, inclosed between hills several

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[1] Bogdo, sacred, and oola, mountain.

hundred feet high, and remarkable for their pyramidal forms. The fragments of rock, both angular and rolled, that cover the valley, were found to be of green clay schist, the same metamorphic greenstone seen yesterday, and a greenish sandstone.

In the forenoon we reached Urga, also called Kuren, the residence of a living Buddha.

Dec. 14. Left Urga for Kiachta, which place we reached on the 21st December. The country between these places was covered with snow, concealing its geological character. Our road lay through the hills to the eastward from the Orkhon river, crossing its tributaries, the Kara Gol and the Iro Gol.

Through the first two-thirds of the distance the few outcrops seen were of rocks similar to those seen near Urga; at Iro Gol I found chloritic granite.

A great steppe deposit, apparently of loose argillaceous sand, fills the valleys, and, extending over the lower parts of the crests of the ridges, leaves the higher peaks isolated like the islands of an archipelago. This is part of a very extensive deposit which, from its position here, must be continuous through all the lower course of the Orkhon. It would seem to be the same deposit that forms the broad steppe south of Kiachta, and is visible, I think, in the terraces of the Selenga as far as Lake Baikal, and in the tables on either side of the Angara at Irkutsk.

The barometrical measurements of the Russian Academicians, MM. Fuss and v. Bunge, have shown that that part of the continent which they crossed, between the Great Wall of China and the Siberian frontier, south of Lake Baikal, is an elevated plateau, bounded on the N. W. and S. E. by mountain ranges from 5000 to 10,000 feet high, from the sides of which the table-land falls gently toward a broad level region in the centre, the mean height of which is not more than 2400 feet.

The skeleton of the plateau is thus a great geoclinal valley, trending nearly N. E., the basis of which, so far as observed, is formed by granitic rocks, and metamorphic strata, probably of Paleozoic origin, and the inequalities of which have been nearly filled up with more recent formations. Of these latter we can, at present, recognize only three, viz:—

1. The great development of lava along the southern edge.
2. The steppe deposit including the Gobi sandstone.
3. The deposits of loam, mentioned in the preceding pages as covering in places the steppe deposit.

The lava formation is apparently the oldest of the three. We have seen, in a former chapter, how a part, at least, of the southeastern edge of the table-land owes its level surface solely to the great thickness of the volcanic rocks, which have thus been able to fill up the hollows between the ridges of granite and metamorphic rocks. The profile, constructed from the measurements[1] of MM. Fuss and v. Bunge, seems to indicate the existence of a terrace from 3000 to 4000 feet high and about 150 miles broad, that forms the S. E. border of the plateau. It is not improbable that this terrace is due, in great part, to extensive lava flows.

The volcanic rocks of Lake Baikal and of the region to the east, the occurrence

[1] Ritter.

of products of this class in place and as scattered fragments at many points on the route across the plateau, and finally the information derived from Chinese authorities concerning the existence within historical times of active volcanoes, among the mountains of Manchuria to the east, and in the Tienshan of the west, all point to a development of volcanic activity, which was formerly coextensive with the area of the present table-land. The remains of this action still make themselves felt in the violent earthquakes that from time to time shake the districts of northern Chihli and the shores of Lake Baikal.

The greater flows of lavas seem to have been predetermined by the fissures of dislocation, formed along the borders of the area that was subsequently to be elevated. Such a fissure we have seen marked by a great fault south of the Lakes Kirnoor and Téhai.

In the present state of our knowledge of this vast region, it is, I believe, impossible to say whether, at the time of the eruption of these rocks, the present depression of the Gobi was or was not under water. That a portion of the southern edge of the plateau was not submerged appears from the fact that where the bottom of the lava formation was visible it was found to rest immediately on the old granitic and metamorphic rocks. This, however, does not preclude the possibility of the existence of undisturbed deposits under the steppe sandstones of the Gobi.

The sea in which the great steppe deposit was precipitated was studded with islands now represented by the ridges and peaks that rise above the plains. The surface of the plains rises everywhere toward these former islands, partly because the deposit in its formation adapted itself partially to the original surfaces of the valleys it fills, and partly from its thickness being increased by the tributary detritus of the islands. The effect of such a combination of circumstances upon the form of the surface, has been discussed in treating of the lake deposits of Northern China. It seems not improbable that the same causes may have operated here as there, in forming many of those lake valleys, the beds of which rest upon the steppe deposit.

The age of this extensive deposit is a question of much interest. If it is contemporaneous with the steppes and terraces of the valley system of the Orkhon and Angara, it seems probable that the sea which left this deposit over nearly all of what is now the plateau, was also contemporaneous, within certain limits, with that great body of water which, extending from the polar ocean to the Caspian, occupied all Western Siberia.

The fact, to which Baron v. Humboldt[1] has called attention, that seals, identical in species, inhabit the fresh waters of the lakes Baikal and Oron (lat. 55° N., long. 119° E.) and the Caspian Sea, seems to refer to that period. The Oron lake is a tributary of the Vitim, and through this of the Lena, in which no seals occur. This circumstance points very clearly to a former water communication between these far separated localities, and the time at which the seals of the Oron became isolated from those of the Baikal and the Caspian falls, perhaps, in the same period with the emergence of the great plains of Northern and Western Siberia, the deposits of

[1] Humboldt, Kosmos, IV, p. 456. Stuttgart und Tübingen, 1858. Pallas. Zoographia Rosso-Asiatica, 1818, p. 115.

which are characterized by abundant remains of the mammoth as well as of *Bos urus* and *Rhinoceros tichorhinus*.

We have seen that although the effects of erosion are generally not very extensive in the steppe deposit, they exist in some places on a large scale. The deeply cut valley in the Tamchintala is an instance, and one that seemed to me could have been caused only by fluviatile action. The erosion in the neighborhood of Bilika Noor, and the presence in the eroded valleys of loam strongly resembling that deposited by great rivers is another instance. This loam was not often seen, indeed it is mentioned in my notes only as occurring in the Mingan hills, at Bilika Noor, and over the steppe deposit near Goshun.

The closing event in the history of the great sea that in comparatively recent times covered so large a part of Asia, extending from the pole to the Caspian and Black sea, and from the Ural mountains to near the Great Wall of China, was the disappearance of its waters from the long trough that reaches from the shores of the Arctic sea, through the Barabinsky steppe to the Aralo-Caspian depression.

It appears to me that the ancient physical geography of this vast region, and the effects of its elevation, present one of the most interesting and important fields of exploration. Whether we consider the meteorological changes that must have been brought about by the upheaval of so large an area, or the influence of this great water communication and its currents on the distribution of existing genera, the geological phenomena that have affected this broad belt of the great continent have, beyond doubt, had an important influence on the recent history of our planet.

In the following table I have recapitulated the few leading events in the geological history of China and Mongolia which seem to be recognizable.

	Disturbances.
A. Deposition and metamorphism of the older metamorphic strata of China. B. Deposition of the metamorpic strata of Mongolia.	Uplifts apparently of various ages and directions, of which the surface effects are mostly obliterated.
C. Deposition of the great Devonian limestone formation.	
D. Eruption of the older porphyries of the Sishan, west of Peking. E. Deposition of the Chinese Coal measures. F. Eruption of the younger porphyries of the Sishan.	Sinian revolution forming the N. E. S.W. system of uplifts. Emergence of all China Proper.
	Submergence of Mongolia.
W. Eruption of the trachytic porphyries of Kalgan and the Gobi Desert. X. Eruption of the volcanic rocks of S. Mongolia and the Baikal region. Y. Deposition of the steppe deposits of the Gobi Desert.	
	Commencement of the emergence of the plateau. Formation of the great dislocation along the southern edge of the plateau. Supposed change in the course of the Hwang Ho, and formation of the chain of northern lakes.
Z. Deposition of the lake loam of the northern lakes. Beginning of the delta of the Hwang Ho.	
	Deepening of the channel of the Hwang Ho between Shansi and Shensi, and of the gorge of the Yang Ho, and consequent drainage of the northern lakes.

CHAPTER IX.[1]

GEOLOGICAL ITINERARIES OF JOURNEYS IN THE ISLAND OF YESSO, IN NORTHERN JAPAN.

The following notes were taken during journeys made in the service of the Japanese Government, in the summer and autumn of 1862. As the very small population of this northern island is composed almost entirely of fishermen, it is confined to small villages scattered along the sea-shore. The only roads are those connecting these hamlets, with the exception of rare bridle-paths penetrating the interior. The mountains west and north of Volcano bay are covered with dense forests and a denser undergrowth of a kind of bamboo, so close-set that the country is impenetrable, excepting by wading in the beds of torrents.

Thus the geologist is obliged to content himself chiefly with the sections exposed on the sea-shore.

Hakodade, the seat of the Viceroyalty of Yesso and Krafto,[2] is at the foot of a peak about 1,150 feet high, connected with the main island by a low, sandy neck.

The rock that forms this island-like promontory is apparently a pluto-neptunian product resulting from the metamorphism of trachytic tufas and conglomerate-breccias. Where I examined it, it consisted of a fine-grained felspathic base, containing—

1st. Felspar in oblong crystals, from very small to one-third of an inch in length. These were white, highly fractured, and frequently showed triclinic cleavage.

2d. Quartz in pellucid grains, very irregularly distributed, in places absent, in others equalling the felspar.

3d. Hornblende in small prisms.

4th. Magnetic iron in grains.

The rock in this locality has somewhat the appearance of having been broken up and partially refused, but more generally it shows signs of stratification, and I have referred it to the extensive marine deposit formed out of the debris of volcanic rocks.[3]

On the northern slope of the peak is a terrace of recent gravels raised 100 feet or more above the bay.

Between the hills of the main island and the sea there lies a plain the surface of which slopes gently toward the water, where it terminates in places in high bluffs,

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[1] See Map, Pl. 8.

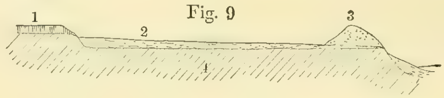
[2] Sagalin of the Russians.

[3] This is probably the rock described in Com. Perry's Japan Expedition, as granite with crystals of turmaline.

in others in low terrace steps. Near Kameta this terrace is covered with a few feet of clayey sand, underneath which is a bed of whitish clay used for fine tiles; more generally these terraces are a bluish, sandy clay, rich in recent shells, and fringing the less precipitous shores of most of the Japanese islands.

First Excursion. May 24th, 1862.—Leaving Hakodade we crossed to the main island by the low neck of land. This is formed by a bar of stiff clay, perhaps of the same age as the terrace deposit, which lies a few feet above high-water, and is covered with drift sand. Along the eastern edge of the neck, the sand has been raised by the winds into hills, sixty to eighty feet high, the shapes of which change with every storm, excepting where protected by a sufficient growth of wild rose-bushes. Behind these hills the ground is swampy, the water finding a very slow drainage through the sand.

Fig. 9



1. Loam. 2. Marsh. 3. Drift sand. 4. Stiff clay.

Following the beach of the northern shore of the bay for several miles, we turned off at a small village, and, ascending a creek, entered the fertile valley of Ono, a broad marshy plain on which are some of the principal farms of the island. An inferior rice and silk are said to be among the chief products.

May 25th.—Branching off from the main road, a few miles beyond the village of Ono, and following a mountain brook, we reached the lead mines of Ichinowatari.

These mines lie at the entrance to a small valley, on the sides of which the outcropping rocks, containing the veins, are black and gray argillites, slightly calcareous, and highly metamorphosed, in alternating beds; the gray rock being apparently the younger. These are associated with greenstone, whether eruptive or metamorphic was not ascertained, which occupies most of the valley to its head. On the summit of the ridge the greenstone was found by Mr. Blake to be succeeded by a shale, from which he took a calamite, and this again by the black rock already mentioned.

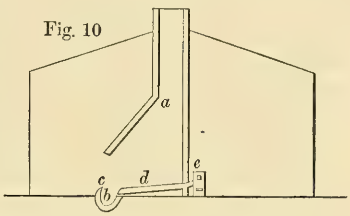
The veins occur in all of the above rocks; the predominating veinstone being of magnesite bearing; in nodules, threads, and impregnations, black and yellow zinc-blende, iron pyrites, galena, and, in places, copper pyrites. The wall rocks are highly impregnated with small cubes of iron pyrites.

In Japan, as in China, the want of pumping machinery prevents working to any considerable depth below the adit level. The galleries in this mine were tolerably well timbered, but low and narrow. From ignorance of the use of powder in blasting, their means of attacking the rock were—till the application of powder in mining was introduced by us—confined to the use of pointed instruments, a miner's pick with one point, similar to our own, a hammer and gad with handle, like the German *Eisen*, completing the outfit. The ore is roughly assorted by hand, and then passed under dry stamps. I was not a little surprised to find, in the mountains of Japan, stamps constructed on the same principle as our own, though the workmanship and efficiency are far inferior.

An overshot water-wheel turns a slender shaft, armed with long cams, by which the stamps are raised. These last are ten in number, of wood, about nine feet long and four inches square, and bear inserted in their lower ends, iron heads from one and a half to two inches square. Each stamp acts in a separate stone mortar, set into the ground, and powders thirty kan,[1] or two hundred and fifty pounds of ore per day of twelve hours. After being stamped the ore is sifted and sent to the wash-house, where it is concentrated to a very pure schlich by hand washing in wooden pans. This work is done mostly by women.

The furnace in which the ore is smelted is a cavity in the ground, lined with charcoal powder kneaded with puddled clay, forming a hemispherical crucible (*b*) about 14 inches broad and 10 inches deep, with an underdrainage. In front is an earthen shield (*c*) to reflect the force of the blast, which enters through a clay nozzle (*d*) from the box-bellows (*e*). The greater part of the smoke, etc., passes off through a large chimney (*a*).

Fig. 10



The crucible is lined with charcoal, and when fully dried about 80 lbs. of ore is added and covered with charcoal. When half melted 30 per cent. of pig-iron in lumps of about an inch cube is added. As soon as about one-half of the galena is freed from its sulphur, the whole is stirred. After about two hours the coals are withdrawn, the blast stopped, and water is thrown on the bath to cool the first layer of matte. This is repeated six or seven times till the surface of the lead is free, when it is cast in bars, the matte being thrown away.

We have in this operation the simplest form of the precipitation process, the *Niederschlag Arbeit* of the Germans.

The greatest production at these mines was in 1860, when, during three months, it averaged about 600 lbs. daily; at the time of my visit it was about 80 lbs.

The running daily expenses of production for this small result of 80 lbs. were nearly as follows:[2]—

30 miners, averaging	6 cents	$1 80
30 coolies, at	8 "	2 40
7 overseers, at	5 "	35
1 carpenter		8
26 ore dressers, averaging	3 cents	78
2 stamp tenders, at	4 "	8
1 smelter		8
2 smelter's assistants, at	4 cents	3
200 lbs. of charcoal		17
30 lbs. of inferior pig-iron,		16
		$5 98

[1] 1 Kan is equal to about 8 lbs.

[2] Assuming the ichibu to be worth $0 33.

The miners working in ore are paid according to the weight and quality of the ore extracted, receiving one cent for every 10 kans, or 80 lbs. of best rough ore, and one-half a cent for the same quantity of inferior.

When not working in ore they are paid by the running foot on the gallery and the hardness of the rock, receiving per running shak,[1] or foot, 60 cents for the hardest rock, and 14 for the softest, the average at these mines being 30 cents. One man can advance a gallery one foot, in the hardest rock of these mines, in five days.

The timbering of the levels costs 10 cents per running foot, the wood growing in the vicinity.

May 28th. Leaving the mines, we returned to the main road, and crossed the watershed of the peninsula. The rock is concealed, but judging from numerous fragments on the surface the older rocks of the ridge are covered with volcanic conglomerate.

About twelve miles to the N. N. E. we saw the half ruined cone of the volcano Komangadake, also called the Sawaradake. In the valley lying between us and the peak, lay a picturesque lake surrounded by forests and meadows, and its banks overhung with a rich vegetation. Beyond lay the beautiful Volcano bay. Descending from the ridge we passed the lake, and stopped for the night at the small village of Skunope.

May 29th. Leaving Skunope we started to ascend the volcano. As our way lay through the forest, coolies were sent ahead to clear a path in the underbrush. For several miles we were in a dense wood much like a New England forest; the prevailing trees being grand specimens of magnolia, beech, birch, maple, and oak, with immense vines of grape, ivy, etc., clinging to their trunks and hanging from the boughs.

We came out of the forest upon the gentle foot-slope of the mountain, here covered with a deposit of pumice that extended from where we stood to the summit, in the shape of a stream several hundred yards broad. Leaving the horses, and keeping on the pumice, we soon reached the steeper ascent. The sides of the volcano have been covered with a growth of large trees, where now only dead, white trunks are left, some standing, but the greater number fallen. Many of these lay in our path, while some, standing in their original positions, were surrounded by the subaerial deposit of pumice which reached several feet above the roots.

We reached the edge of the crater at a point below the highest peak.

I was told that the Sawaradake was formerly a single cone, but that seven or eight years before our visit this fell in, the occurrence being accompanied or preceded by a severe earthquake, and an eruption of hot water and pumice, the sand of which was carried by the winds as far as the Kurile Islands.

The crater is now several hundred feet deep, with steep walls, and entirely open toward the sea on the east. The bottom is formed by a convex mass of pumice which extends with an unbroken slope through the opening to the sea-shore.

Great cracks traverse this plain in every direction, distinguishable, from our position on the summit, by their raised, yellow edges, forming long ridges, as though gigantic moles had undermined the plain, and by rows of steam jets

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[1] The shak is about one-fifteenth of an inch shorter than our foot.

The view in the distance is grand. On our left the shore of the beautiful Volcano bay forms a long, sweeping curve, parallel to which the mountains in the background, covered with dense forests, appear in all the shades of green, blue, and purple, as they stretch away on the far horizon. Far over the bay, rising as it were from the sea, are several beautiful cones, long quiet, covered to the summits with vegetation, while nearer, though seemingly among them, is the semi-active Usu, a ruined cone whose yellow, sulphur-coated cliffs glisten even at this distance.

We descended into the crater by a talus of pumice, and crossing to the north side came to the edge of a secondary crater, or pit, in the plain. This was about 600 feet in diameter, with precipitous sides on which the stratification of the mass of pumice that fills the bottom of the great crater is distinctly visible.

From the bottom and sides of this pit columns of steam were rising, incrusting the walls with crystals of sulphur and salts. This inner crater must have been formed after the falling in of the cone, and was, perhaps, the point of exit of the ashes that fell after the breaking in of the peak.

On examining the long fissures that traverse the plain, their sides were found incrusted with delicate crystals of sulphur and sulphate salts, while the pumice walls were half turned to a bright red clay, impregnated with these crystals. Putting my thermometer, which was graduated only to 80° C., into the steam, the mercury instantly ran up to that point.

The recent covering of pumice conceals, in most places, the true structure of the mountain, as it forms a deep mantle over every slope not too steep to retain it. This product is grayish-white, very irregular in its porous structure, and contains numerous crystals of felspar and grains of a translucent, greenish glass. It is undergoing rapid disintegration. Bombs of black scoria were found containing crystals of white felspar, and showing transition, in streaks, into pumice characterized by the same contents as that just described.

Blocks of a grayish trachytic lava, abounding in crystals of triclinic felspar and grains of the greenish glass, mentioned above, occur in the crater, and seem to be the rock of which the pumice and bombs are a variety.

The western side of the crater wall is the highest, and owes its better preservation to a broad dyke of rock consisting mainly of a dark paste with greenish-white crystals of triclinic felspar, hornblende, and magnetic iron. The dyke has a tabular structure, the plates being upright in the middle and horizontal on the sides, forming there a right angle with the cooling surface, as is the case with columnar structure. The rock traversed by this dyke was found very much disintegrated.

Without visiting the top of the northern wall we could clearly distinguish the original outer mantle of the volcano, in the exposed edges of different colored strata, while just under the top of the western wall a stratified remnant of what was probably the old cone remained. The greater part of at least the western and northern walls appear to be of trachytic rock.

The general appearance of this mountain produced upon me the impression that it had, before this, been a ruined cone, but was rebuilt by an eruption of pumice to be again broken down and given over to the levelling solfatara-action.

Descending by the same route we returned to Skunope.

May 31st. Leaving Skunope in the morning, we travelled northward, first through a thickly wooded, swampy district, with corduroy road, then over a soil of volcanic ashes, till we finally reached the sea-shore, when turning eastward, we skirted the northern foot of the volcano, and crossing the outlet of the lake reached the fishing village of Shkabe.

The northern slope of the mountain was formerly covered with timber reaching high up its side, and now represented by a forest of dead trunks extending over thousands of acres. The trees were probably killed by the shower of pumice which covered the surface to the depth of from six inches to two feet. On a large proportion of the trees the bark is intact, and they show no signs of the action of fire. A fresh undergrowth was springing up, at the time of our visit, and of this the climbing plants seem to have been the first to start into life.

In the side of a gulley in the bluff, I observed the following series from younger to older:—

1. Layer of pumice, two feet thick.
2. Vegetable mould with roots of grass six inches.
3. Layer of pumice, three to five feet.
4. Thin layers of pumice and sand, apparently an ancient beach.
5. Volcanic conglomerate-breccia.

This section is repeated in all the cuttings observed at the foot of the volcano.

At Shkabe there are several hot springs used for bathing. One of these, rising on the beach and bubbling strongly, has a temperature of 75° C.; and in another rising in a cold stream, but protected by wooden tubbing, I found 70°. The water of these springs has a slight odor of sulphuretted hydrogen.

June 1st. Soon after leaving Shkabe we passed an outcrop of quartziferous porphyry, showing columnar structure, and remarkable for its richness in double pyramid crystals of pellucid quartz associated with white felspar in a compact gray paste. The volcanic conglomerate-breccia was the prevailing rock, but in places the bluff was formed of an apparently younger deposit of sandy clay. The beach was in many places covered with a layer of magnetic iron sand, from the disintegrated volcanic rocks, well concentrated by the action of the surf.

From Shkabe eastward many fragments of vein quartz were seen on the beach.

At the mouth of the Kakumi creek we left the sea-shore, and following the wild valley rode a few miles inland to the mines of Kakumi. Here the hills are formed of greenish and gray argillaceous rocks in places brecciated, in others metamorphosed to an euritic rock. These are traversed by dykes of a peculiar white porphyry.

This porphyry has a compact paste, generally very white, sometimes gray or greenish, yielding fire with difficulty with the steel. In this are scattered grains, and especially double pyramid crystals, of quartz, which form from a few per cent. to one-third the volume. In rare instances it contains crystals of a white triclinic felspar. Mica and hornblende are never present and rarely chlorite. It contains almost always small cubes of iron pyrites.

In weathering it changes to a white kaolin-like substance often discolored by the oxidation of the pyrites.

It occurs in dykes, and often shows columnar structure.

Porphyry of a similar character occurs at several points on the island.

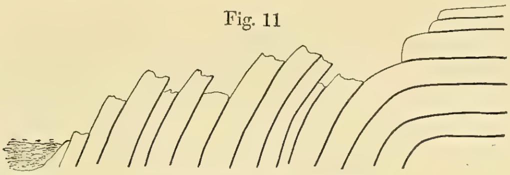
Ascending the creek, greenstone was found to succeed to the argillaceous rock, and seems to be the only formation for at least several miles up the valley. In this are the copper bearing veins, six or eight inches thick, of quartz, containing iron and copper-pyrites, a little zincblende, and some calcspar in cavities. The mine had only been opened a short distance.

Near the house there is a warm spring, with a temperature of 48° C., rising in the argillaceous rock.

June 4th. Leaving Kakumi, in the afternoon, we rode about three miles to the fishing village of Wosatzube.

Just east of the village is a promontory formed by an outcrop of beds of black hornstone.

Fig. 11



Hornstone Strata. Cape Wosatzube.

This rock is stratified in well-defined layers from a few inches to several feet in thickness. It has a velvety-black color, more rarely with lighter shades, breaks with conchoidal fracture, and shows, when wetted, a lamellar structure the layers of which are thin as paper, of black and dark-gray shades. In places it is slightly brecciated, the interstices being filled with opalescent chalcedony in layers of infiltration.

I may add that the Japanese mining officials who accompanied us, stated that a similar rock occurs in close connection with the coal beds on the eastern coast of Yesso. The trend of the strata at Wosatzube is N. 40 W., the general dip being northeasterly.

Off the point just described is a spring which bubbles up from the bottom, very strongly at low water, and quite visibly at high tide.

June 5th. The country east of Wosatzube being impassible for horses, we embarked in a boat propelled by sixteen rowers, and after a voyage of between three and four hours reached the fishing village of Totohoke. The scenery was very grand, as the coast is here formed by a wall several hundred feet high, and washed by the sea at its base. Innumerable waterfalls, some of them very high, and all beautiful, were seen at the heads of ravines, or falling like veils over the high coast bluffs. These cascades occur along the entire Japanese coast, and the early navigator Vriess mentions them at almost every step in his narrative.

The rock forming this coast wall seems to be volcanic tufa-conglomerate, with lava dykes. On examining the rock of the bluff west of Totohoke, it was found to be indistinctly stratified and made up of round and angular fragments of trachytic lava inclosed in a gray matrix more or less hard, with earthy fracture, and contain-

ing perfect crystals of hornblende and altered felspar, with scattered grains of quartz. The rock often presented in the fresh fracture all the appearance of an earthy lava, its detrital origin being most apparent on the weathered surface. The stratification dips northward toward the sea.

Totohoke lies at the foot of the volcano Esan.

June 6th. We ascended on horseback to the crater of Esan volcano, which forms the eastern point of the peninsula.

This, also, is a solfatara, its latest eruptions, of which there is no record, having been confined to flows of sulphurous mud. No pumice was seen, and the fragments of rock that formed the ejecta were of the same character as the walls of the crater, excepting some blocks that seemed to be pieces of the white quartz porphyry found at Kakumi, which had been torn from the interior of the mountain.

The crater, which seemed to be larger than that of the Sawaradake, is divided unequally by a high ridge of detritus. The walls, where observed in our passing examination, were found to be so altered by the constant action of acid vapors, as to render the character of the original rock very obscure, but I thought myself able to trace a similarity, through a series of specimens, between this and the more common ejected blocks. These latter consist of a dark gray cellular lava of porphyroidal texture. The crystals of felspar, which are numerous, are changed to a white earth, isolated specimens still retaining numerous crystals of hornblende; but the most characteristic feature is the abundance of quartz. This last mineral is present in well-defined, double pyramid crystals and in grains one-eighth to one-third of an inch in diameter. The grains are both limpid and milky white, and opalescent. They are highly fractured, and often present the appearance of having contracted and cracked in passing from a gelatinous to a hardened condition. There is often a strong resemblance between these rocks and the fragments inclosed in the tufa-conglomerate of Totohoke.

The walls of the crater are rapidly disintegrating and falling, to be converted into clay impregnated with sulphur, alum, and other salts. Everywhere the scene is one of ruin. Here is visible on a grand scale the decomposing action of sulphurous acid and steam, the effects of which we see in the altered trachytic rocks of Hungary, and still progressing on a small scale in the Neapolitan solfatara. Nowhere have I seen so well exhibited the levelling power of nature when she brings into action her more active agents.

Steam surrounds us, issuing in jets from fissures on the sides of the crater, and rising slowly, as smoke from a smouldering fire, out of the taluses of debris. But the main vents are small, mud craters or geysers. Those which we visited were in the centre of one of the divisions of the crater. They were springs or pits, each covered by a great vault of hardened mud, like an immense bubble or an inverted bowl, from ten to twenty-five feet high, the sides and roof from six inches to two feet thick.

These quake with the constant reverberation of the struggling steam and mud, which last, judging from the sound, must rise to near the surface. The inner surfaces of these vaults are lined with sulphur in massive layers, in crystals, and often in long stalactites, and the vapor is highly charged with sulphuretted hydrogen.

While we were here drops of scalding mud were incessantly thrown out, but regular mud-flows appear to be very rare.

The superintendent of the sulphur works informed me that when new vents open, mud and large blocks of rock are thrown out with much violence. Such blocks cover the interior of the crater, and have been already mentioned; they are frequently almost entirely decomposed by the action of the gases.

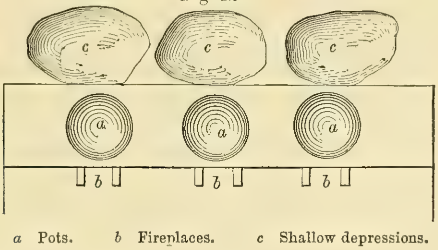
From an extinct vent I traced a stream of mud, following the bed of a gully, for several hundred yards. It is hard, compact, and filled with small crystalline needles of sulphur, the longer direction of which was found to be invariably at right angles to the nearest surface, by which either the heat or moisture, or both, escaped. These crystals occur equally distributed throughout the mass the whole length of the stream, and produce, on a small scale, a tendency to columnar structure. They cannot, considering their position, have been crystallized until the mud was quiescent and hardening, and as the solidification depended on the escape of the moisture that rendered it fluid, it forms, I think, a good illustration of the fact that columnar structure is not necessarily a result of cooling, but rather of the escape of the "vehicle of fluidity," whether this be heat or water, or, as here, both combined.

The stream in question appears to be the result of a single flow filling the inequalities in the bottom of the gully, and is in places several feet deep.

The government has large sulphur works on this mountain, with which the production of alum was formerly combined. The material used, from which the sulphur is extracted, is the debris formed by the ever-falling walls of the crater, and which is said to contain from 25 to 50, and even 60, per cent. of the mineral, in layers and impregnated through the mass.

Without further preparation than being broken with the hammer, this raw material is put into three iron pots over a fire. Each of these vessels is composed of two parts, a cylinder and a hemispherical bottom or pot on which it stands, the whole being about two and a half feet deep and two feet in diameter. After melting, the impurities seem to settle to the bottom, and the top is ladled out into shal-

Fig. 12



a Pots. *b* Fireplaces. *c* Shallow depressions.

low depressions in the ground. When this is cooled, it is a hardened mud filled with crystals of sulphur in needles, their longer axes at a right angle to the surface of the cooled mass, and the whole product differs from the mud described above, as

having flowed from a vent, only in that the artificial product is richer in sulphur. In this instance the "vehicle of fluidity" was undoubtedly heat acting through melted sulphur.

This first rough product is remelted in similar pots, and then filtered through sacks, at first allowing the liquid sulphur to pass, by its own weight, and finally squeezing it gently under a lever. From these filters it falls into tubs the shape of which it retains on cooling. The blocks thus obtained are broken, and the cooling surface, to the depth of two inches, being of a dark color, and, perhaps, less pure, is remelted to obtain yellow sulphur; the interior of the blocks is yellow and highly crystalline.

The produce at the time of our visit was about 5,600 lbs. daily. The officials stated in round numbers that, everything included, the cost of producing 32,000 lbs. was about 80 rios, or $103, the same quantity bringing about $385 at the Hakodade market.

The iron pots cost for the top pieces $2 66 each; for the bottoms $6 60. The bottoms last from 30 to 60 days.

Continuing our journey we descended the western slope of the mountain to Nitanai, on the sea-shore.

June 7th. Leaving Nitanai, we rode along the sea-shore to Kobi. Near Nitanai we passed the outcrop of a bed of white infusorial earth raised several yards above the sea. The reader is referred to Mr. A. M. Edwards' Letter (App. No. 3) for the highly interesting results of his examination of this material under the microscope. Mr. Edwards has discovered a close resemblance between the organisms contained in this deposit, and those of the stratum under Richmond and Petersburg, Va.; and a still greater similarity to those of the extensive deposit along the California coast, the resemblance in the latter instance extending even to identity of species among the *Diatomaceæ.*

At Kobi an attempt had been made to smelt the magnetic iron sand from the beach in a blast furnace of the foreign pattern. One of our party, Mr. Takeda, a Japanese officer of rank, who has done much to advance, in his country, the knowledge of military engineering and navigation, was commanded by the Imperial Government to construct a large furnace for smelting iron ore after the foreign method. Such a thing had never been seen by a Japanese, but without further plans or specifications than he found in a Dutch work on chemistry, Mr. Takeda built a furnace about thirty feet high, after a very fine model, with cylinder blast moved by an excellent water wheel. Unfortunately, owing to the absence of all details on the subject in the only book he had, the blast obtained was only a fraction of that required, and the bricks used in the construction were not sufficiently refractory. Thus the affair was a failure after smelting a few hundred weight of iron. The incident, however, is an illustration of Japanese enterprise. I will add that the experiment was repeated by order of the Prince of Nambu, in order to work an excellent ore of magnetic iron on his property, and furnace after furnace built, from 20 to 30 feet high, until successful campaigns of several months' duration were obtained.

At Kobi, besides the iron sand of the beach, there is an elevated, ancient beach, now from 50 to 100 feet above the sea, containing a bed of iron ore of a similar origin, the lower half cemented by oxidation to a solid mass, and changing to

brown oxide, the upper portion less oxidized and retaining more of the original character.

How many deposits of iron ores may there not be that owe their formation to a similar cause, the destruction of ancient eruptive or metamorphic rocks, and the concentration of their grains of magnetic iron on the surf-washed beaches of former seas?

A few miles further on we came to the outcropping clay slates, which continue, as the tide-washed rock, as far as Shiwokubi (Cape Blunt). From this point on, as far as Oyasu, they are also exposed along the beach and form the hills inland, but are covered between the sea and the hills by the recent terrace deposit, which we have already seen bordering the Bay of Hakodade.

This slate is black and fissile, and is covered, near Shiwokubi by conformable strata of compact sandstone with interstratified seams of slate, and at Oyasu by a sandstone conglomerate containing fragments of the same older rock. These beds are more or less contorted, all the observed strikes of the uplift lying between W. and N. 15° W., averaging nearly N. W.

They are traversed by a great number of dykes of porphyry and greenstone, and by innumerable veins of quartz with pyrites of iron and, in places, of copper.

The porphyry is of the same white quartziferous variety as that at Kakumi, and the same description will do for both. The dykes are very sharply defined, from 10 to 50 feet thick, cutting the slates at all angles. The porphyry is in turn traversed by dykes of greenstone.

The quartz veins cut the slates at all angles, and vary in thickness from 2 to 12 feet. They abound in iron pyrites, one vein four feet thick being massive sulphuret. Some of them were traced between one and two miles inland, the pyrites changing to oxide away from the sea-shore. An outcropping vein at Saidoma showed some very fair ore of copper pyrites associated with iron pyrites, zincblende, and a little scattered galena. The strike of these veins is generally between N. and E., and one of the smaller ones traverses a dyke of porphyry.

It was in one of these that we made the first blast ever fired in Japan.

Between Shiwokubi and Hakodade, a broad *mesa* separates the hills from the sea, rising gently to near the mountain, and then rapidly, and cut into by all the streams descending from the hills. It is covered with a dense growth of weeds but no trees, the latter being confined, along this part of the straits of Tsungara, to the northern slopes of the hills.

At Yunogawa there is an outcrop of black clay slate in which rises a warm spring with a temperature of 38° C.

Entering Hakodade we finished the circuit of the peninsula.

The region thus encircled by our route is a high ridge apparently consisting, in the main, of the metamorphic rocks which have been described as occurring along the sea-shore, having a general northwesterly trend, accompanied by intrusive masses of greenstone and quartziferous porphyries. It is fringed on its northern slope by volcanic tufa-conglomerates that rise, in places, to the lower summits of the crest, and on the southern edge by recent marine strata. I will add that coal is said to have been found in the hills near Mt. Esan.

Excursion to the West Coast.

August 5, 1862. This day and the following one our route was about the same as on the preceding journey, as far as Volcano bay, where, branching off, we stopped at Washinoki for the night.

August 7th. Leaving Washinoki, we found, just west of the village, an outcrop, visible at low tide, of the tufa-conglomerate. It contained fragments of pumice and spines of an echinoderm. The beds are tilted up, the strike being N. 5° W. and the dip easterly.

A little further on we came to an outcrop of nearly vertical beds of a gray argillite, containing a peculiar fossil, having the shape of flattened vermiform tubes and changed to calcite. This organism although indeterminable is characteristic for this argillite, and served to distinguish the rock even when highly metamorphosed at many points on our journey.

I will mention here that between the bay and the mountains west of it, a strip several miles broad is occupied by a recent deposit, similar to that bordering Hakodade bay, and receding in terraces from the water which it faces with a bluff 30 to 80, or more, feet high. This deposit generally hides all the older rocks.

Continuing our journey along the beach, we found the tufa-conglomerate again in place underlying the terrace deposit.

Passing Otoshibetz,[1] the beach is overhung by the terrace bluff, here from 60 to 80 feet high. This recent deposit is a horizontally stratified, sandy clay, abounding in marine shells, chiefly bivalves. Although most of the shells were too friable to be collected, many seemed to have retained a large part of their organic matter, and in several instances I found the dorsal ligament still elastic when wet.

At Yamukshinai, just back from the beach, between this and the bluff, there is a marsh some acres in extent, in which tepid springs deposit a mineral oil of the consistency of tar, which is used by some priests, in the neighborhood, both for burning and in making ink of the kind used throughout China and Japan.

Passing through a settlement of Ainos we reached Yurup.

August 8th. The terrace bluff recedes from the sea at Yurup, forming a bight which is occupied by a broad plain, often marshy, covered with a dense growth of reeds and weeds, twelve to fourteen feet high. Through this plain winds the large creek Yurup.

Crossing this stream we followed the beach to Shirarika. Here there is an outcrop on the beach of a black amygdaloid, containing small spherical cavities lined with a white, transparent, tabular zeolite, and veins and nodules of chalcedony.

Continuing our journey over a plain, now sandy, now marshy, which, at the height of 10 or 20 feet above the sea, forms a narrow belt between the beach and the bluff, we reached Kunnui. The terraces seen during this day were covered with a fine forest growth of deciduous trees and scattered tall pines.

Leaving the sea-shore at Kunnui, we ascended the creek of the same name to a low pass in the crest, which here forms the watershed between Volcano bay and the Japan sea.

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[1] The termination *betz* and *nai* are Aino words signifying river and creek or brook.

The only formation seen was the terrace deposit, till near the divide, when an obscure green wacke was found in place, and near this a greenish-black amygdaloid. Large blocks of granite were also seen here, and this rock is probably in place near by.

Descending to the west we entered the valley of the Toshibetz, a large creek, navigable with small, flat boats, and soon reached the gold washings of Kunnui.

This part of the valley occupies a broad depression, perhaps 15 miles long by 7 broad, and raised several hundred feet above the sea. It has been filled with the recent terrace deposit, and subsequently eroded in part, after which an extensive deposit of auriferous gravels, etc., has taken place over at least a considerable part of the area.

In one of the side valleys the older rocks are exposed, and here the gold bearing drift was found resting, in different places, on an argillite similar to that seen at Washinoki, and containing the same vermiform fossils, in strata striking N. 85° W., and dipping 50° northerly, and on an amygdaloid similar to that on the divide. Not far from here the terrace deposit overhangs the creek in a high bluff. Out of the base of this precipice I obtained a number of well-preserved fossil shells. In the same bed were found Ostreæ, Pecten, Scalaria, Terebratula, Nuculina? Serpula? Corals, Bryozoa, and fragments of a thick shell with cross-fibrous structure. Some of the shells retained, at least in part, their organic matter and nacreous lustre, and one species of Pecten appeared to be identical with a species living in the adjacent seas.

At one end of this bluff is a large rock of the amygdaloid in place, which has been exposed by the erosion of the terrace deposit, and on it are incrustations of Serpulæ.

This amygdaloid contains masses of a green rock resembling jasper, in which are scattered flakes of native copper. Blocks of manganese (binoxide) in the immediate neighborhood seem also to have come from the amygdaloid.

The auriferous gravel occurs along both sides of the river in the form of a plain, which descending gently from the hills faces the stream with a bluff. The whole district appears to have been worked in former times, though when appears to be unknown. Broad and deep canals of considerable length were dug to bring water from up the creek, and a well arranged system of "ditch diggings" seems to have been carried on. All these workings are covered with a dense growth of trees, apparently not differing from the surrounding forest; some seen in the ditches being as much as eighteen inches in diameter. The method of washing the gold does not seem to have differed from that now used by the Japanese.

The principal rocks, that have contributed to form the auriferous drift, are varieties of granite, chloritic and micaceous schists, quartzites, and amygdaloid, with geodes of chalcedony from the last mentioned rock. Rolled fragments of binoxide of manganese are frequent also, perhaps derived from the amygdaloid. The concentrated sand of the washing is principally magnetic iron associated with zircon sand.

The manner of working the deposit is ingenious, and will be understood by referring to the annexed diagrams.

Fig. 13

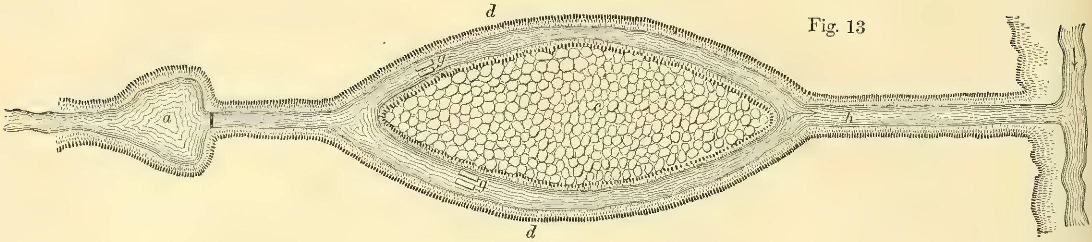
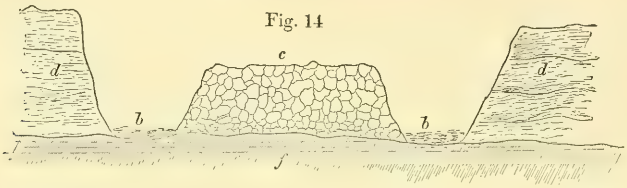


Fig. 14



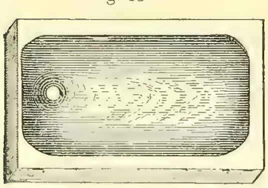
a. Reservoir. *b.* Sluice-ditch. *c.* Rubble of the drift. *d.* Aurif. drift. *e.* Creek. *f.* Bedrock. *g.* Mats.

At the place where I saw this process, the surface of the bed rock, in this case the marine terrace deposit, was sufficiently high above the creek to give a rapid fall in the sluice-ditch.

The bed of a rivulet is chosen for the work. A reservoir (*a*) is dug and dammed, and the bed of the rivulet (*b*) cleaned out and made regular. This done, the banks (*d*) are broken down into the stream where the force of the current concentrates the gravel, carrying off the sand and clay. The workmen then place themselves in pairs up and down the stream near and below the broken-down bank. Each man is provided with a coarse mat, about two feet long by one foot broad, which he places lengthwise in the stream, keeping it down with one foot on the lower end, at the same time partially stemming the current. He then hoes the gravel on to the mat, much of the old gravel going off below as fresh arrives from up stream.

At intervals the mat is carefully removed and washed out into a very shallow tray or batea (Fig. 15), a board about eighteen inches long by a foot broad, hollowed out, and having a circular depression near one end for the concentrated head. Of the black sand obtained on this board, the head containing the gold is saved.

Fig. 15



In this manner the gravel is pretty well exhausted of its gold, very little being obtained by the men farthest down the stream. The working progresses sideways, into the banks, and up stream, the current being kept near the banks as these recede from the centre of the stream. As the space between the banks widens, the coarser material that resists the force of the water is thrown up into a pile of loose masonry (*c*) which increases in length and breadth as the work advances.

Numerous remains of ancient workings, by this method, are found in the neighborhood.

Throughout this region the forest is dense; among the trees I noticed elms and a wild mulberry with black fruit. Fierce, large flies, of two kinds not seen on the sea-shore, swarm in these woods, covering horse and rider, and leaving bleeding wounds wherever they strike. The creek abounds in mountain trout and salmon.

August 14th. Returning to Kunnui on the sea-shore, we followed the beach to the village of Woshimanbe.

August 15th. At this village we left the bay to cross over to the west coast. For several miles the road lay over the terrace belt, here covered with drift. At the divide we found a broad, marshy tract through which a large creek winds on its way to the Japan sea. This stream we descended in a small flatboat.

The prevailing rock across this low part of the ridge was, so far as I could judge, an argillaceous deposit, apparently the same that forms the terraces.

The forest contained, chiefly, large beech, birch, and maple trees, with oaks and scattered firs, and the usual dense undergrowth of cane. The banks of the streams were lined with water willows. The creeks abound in trout, and the gravelly bottom is often nearly hidden by colonies of unio. As we approached the bay of Odaszu the country became more open, and leaving the creek we descended over two terraces of drift to the village of Odaszu on the sea.

The southern shore of this small bay is shallow and shelving, with a broad beach; but the eastern and western sides are rocky, the rocky bluffs descending into the sea, a feature common to all the west coast, so far as we followed it, and indeed to the shores of all the Japanese islands.

August 16th. Leaving Odaszu we continued our journey northward along the coast. Here, also, high terraces face the sea, but they are formed of the tufa-conglomerate formation, the level surface being due to a recent deposit of gravel and sand. This conglomerate is traversed near Odaszu by dykes of a dark gray rock, much weathered, containing crystals of a triclinic felspar, and opalescent chalcedony. The conglomerate at Isoya is traversed by dykes of an amorphous rock containing crystals of triclinic felspar.

Near Isoya there is a deposit consisting of beds of sandstone, argillaceous material, and volcanic ashes,[1] with fragments of pumice, and also of the argillite which has been mentioned as occurring at Washinoki and Kunnui with a vermiform fossil. The pieces of pumice contain beautiful double-pyramid crystals of quartz. This deposit is younger than the neighboring tufa-conglomerate, which had suffered much from erosion before the deposition of the beds in question. It continues northward till it abuts against a mass of volcanic rock, that forms the headland south of the mouth of the Shiribetz river. This stream rises nearly north of Cape Edomo, and flows westward through a fine, broad valley. All the gravel brought down by the river seemed to be trachytic detritus.

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[1] For the interesting results of a microscopic examination of this material, see Mr. Edwards' Letter (spec. No. 11), Appendix 3.

Crossing the valley of the Shiribetz we came to the foot of the Raiden promontory, a bold headland presenting vertical cliffs toward the sea, and apparently made up of lava flows and tufa-conglomerate. In crossing this mountain we frequently found fragments of a black scoria with long-drawn cells.

After a laborious journey of several hours we descended into a deep and gloomy gorge containing a warm spring. Here again we found the same variety of white quartziferous porphyry that we had seen at Kakumi and elsewhere. It is impregnated with iron pyrites which in places is represented only by cubical cavities containing sulphur. The rock traversed by this porphyry is of a brecciated argillaceous character, resembling that at Kakumi. It is from this rock that the springs flow, with a temperature varying, in different ones, from 46° to 50° C. These rocks are exposed only in the bottom of the ravine, on either side of which they are covered by the volcanic formation.

August 17th. Rising from the ravine we continued our journey over the northern part of the Raiden, the outcrops here, as yesterday, being of a gray trachytic lava with a tendency to tabular structure. This continued till we descended at the creek Nibitzunai to a terrace that reaches many miles northward and eastward, low near the sea, but rising rapidly toward the mountains. Skirting this for a few miles we reached Iwanai.

August 18th. At Iwanai we left the sea and made an excursion to the volcano Iwaounobori[1] about thirteen miles inland.

The first five miles of the road lay over the terrace which, as we approached the mountains, rose very rapidly. During the first mile or two, after leaving the sea, the surface was covered with a dense growth of long-jointed grass, six or seven feet high, to which succeeded the usual forest of large maples, oaks, mountain and white-ash, beech, birch, fir, and scattered magnolias, filled in with an impenetrable undergrowth of cane eight to twelve, and even fifteen feet high. The road through this region, being deep with mud which was full of sharp pointed stumps of the cane, was one of the worst I have ever seen.

Entering the mountains we passed through a crateriform valley, once the bed of a lake, and, ascending to a pass in the hills beyond, we saw, beneath us, a beautiful little lake. On the other side of this rose the volcano, or rather solfatara, with its yellow, sulphur-coated cliffs. Here again the regular slopes and symmetrical outlines of an undisturbed cone are entirely wanting; the outer as well as the inner walls were rocky precipices, and the ruin seemed greater than at Esan. We reached the summit without much difficulty.

The present mountain is evidently only part of the skeleton of a former cone of large size. The predominating formation, from the spurs at the base to the summit, is a dark gray volcanic rock, showing in places a tendency to stratiform structure, and apparently of the trachytic family, the chief ingredient being crystals of a white felspar.[2] The former mantle seems to be still represented by fragmentary

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[1] Japanese. *Iwaou*, sulphur; and *nobori*, a term for mountain, from *noboru*, to climb.

[2] With the exception of one specimen of rock, and a few minerals, the entire collection of rocks, shells, etc. from north of Odaszu, was lost by the wreck of a junk on the way to Hakodade.

remains of a stratified deposit seen here and there, about the base, and fragments of scoriæ were found in the neighborhood.

There are several small crateriform depressions at different points near the summit, filled to the level of the lip with sand and clay, and forming small plains surrounded by rocky sides. In one of the walls a compact black rock, either a dyke or the remnant of a lava flow, was observed.

The Iwaounobori is the central one of three volcanoes, which lie in a straight line running about N. N. W., S. S. E., and this is also the trend of a broad belt, within the limits of which the solfatara action is most developed, both across the summit and on the outer walls.

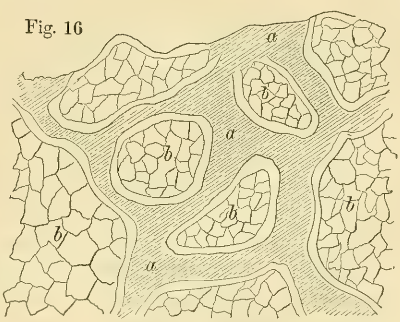
Throughout this belt the rock, wherever not covered by the products of decomposition, is found to be traversed by countless fissures, more or less filled with sulphur. Wherever the filling is incomplete, small jets of steam and gases are still seen to issue forth. Several trials, made by inserting a long chemist's thermometer as far as possible into different fissures, gave a constant temperature of 98° C.

The steam has a strong odor of both sulphurous acid and sulphuretted hydrogen. It has an acid reaction on litmus paper, which is especially strong when the condensed drops, that hang on the sulphur crystals in the cavities, are tested. Beautiful crystals of sulphur, a quarter of an inch long, were rapidly formed on the bulb of the thermometer.

Excepting at the steam vents, which are not more than from one to five inches in diameter, the fissures are closed up with sulphur at the surface, but by breaking away a few inches deep, cavities are exposed lined with a bristling mass of most beautiful straw-colored crystals of this mineral, made up of brilliant steep pyramids connected in the line of the longer axis. Unfortunately, they were too delicate to bear transportation.

On a precipitous part of the outer wall of the mountain, where a large mass of rock seemed recently to have fallen off, I saw an interesting exhibition of the action of the gases. The rock is seen to be traversed by a perfect network of sulphur veins (*a*) which seem to occupy the positions of the cracks common to all rock. The trachytic rock (*b*) is tolerably well preserved in the centre of the blocks, but toward the circumference it is more and more disintegrated, and has assumed the form of concentric layers, the outer shell being changed to a white earth. It seems not improbable that this condition may exist through a large part of the mountain, thus forming a great *stockwerk* of sulphur.

Fig. 16



a. Sulphur. *b.* Rock.

The only way in which I can account for this structure is, by supposing that the disintegration of the rock, which formerly occupied the spaces now filled with sulphur, took place when the water, which now appears only as steam, stood at a

higher level in the mountain, making it a mud volcano, like Esan, and exuding the products of decomposition as fast as formed. On the withdrawal of the water to a lower level the abandoned network of fissures was filled by the decomposition of sulphuretted hydrogen.

At another place, in the walls of one of the small craters near the summit, there is an instance that would seem to illustrate the action of the gases and steam without the presence of water as such. The black rock, already mentioned as occurring in the wall of one of the craters, is visible in different stages of alteration. In places it was observed to have the concentric structure assumed by many rocks during the first period of disintegration, and by which the polygonal form of the blocks, into which all bodies of rock are subdivided, is lost as each succeeding shell is removed. In this case the outer shell is white and earthy. Again the same rock was found altered to the centre of each block, the shape remaining, to a soft, pasty, white clay, quite tasteless. Often in the centre of a snowy white mass of this clay would lie a core, equally soft, but black, the line of separation between the colors being well marked. In places, where the alteration was in the first stage, an alum salt was found forming an efflorescence on the surface of this black rock, possibly as one of the first products from the decomposing felspar.

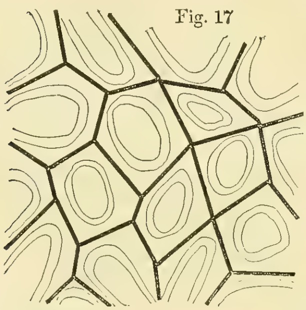


Fig. 17

An emerald-green soft mineral occurs incrusting, to the depth of a line or more, the walls of the gully where these phenomena were observed.

On the west side of the peak, in the valley which drains the craters, there was formerly a spring of chalybeate water, which has left quite a deposit of oxide of iron filled with the leaves of a cane, apparently of the same species that covers the surrounding country. At present there is no cane on this part of the mountain, although it grows within a few hundred yards of the spot. This space, which is bare of cane, abounds in Winter-green (Gaultheria) with white berries.

In close proximity to this deposit a white altered rock, filled with threads of sulphur, attests the former action of the gases in this spot which is now removed from the nearest field of activity.

From the summit of the Iwaounobori I counted fifteen mountains, all of which seemed to be of volcanic origin. Among these I include Esan, Sawaradake, and Oussu, all solfataras, which, from their ruined condition, I would not have recognized as volcanoes at this distance had I not known them to be such.

A few miles away to the S. S. E., beyond the broad valley of the river Shiribetz, rose a magnificent cone also called the Shiribetz. This cone is the most symmetrical of any that I have seen, not excepting the beautiful Fuziyama, the pride of the Empire. Of its height I had no means of judging, but I thought it could not be less than 6000 feet. It rises from a broad plain, at least the slopes visible to us merged gently into the sweeping cross curves of the valley of the Shiribetz river. The unbroken surface of its sides was covered from base to summit with vegetation,

either forest or cane, which appeared to us in the distance like a mantle of green velvet. Many other well-shaped cones were visible in the distance.

Just N. N. W. of the Iwaounobori there is a cone somewhat lower than the peak of the solfatara, with a well preserved crater, so near that it seems to be partly within the circumference of the foot-slope of the Iwaou mountain. As I have said before, it is in a line with its neighbor and the Shiribetz, and this direction is repeated in the zone of the solfatara activity on the Iwaou mountain, a coincidence that would seem to point to a fissure connection between the three peaks.

The government has sulphur works on this mountain, in which fourteen caldrons are kept at work. The production is about 64,000 pounds per month, costing for—

Labor of all kinds and for fuel per month	$74 50
Rice for workmen	41 00
Salt and miso for workmen	4 00
Straw sandals for workmen	6 50
Transportation by horse to Iwanai	57 25
Total for 64,000 pounds	$183 25

August 20th. We returned to Iwanai.

August 21st. Continuing our journey northward, we rode along the beach to the mouth of the Shiribuka creek, where the coast line, turning off to the northwest, marks the southern shore of the peninsula south of Strogonof bay. Following this shore we left the terrace plain of Iwanai bay. During the rest of the day we saw only the tufa-conglomerate formation, which, traversed by numerous dykes of volcanic rock, faces the sea in bold bluffs, to pass which we were at last compelled to take a boat to carry us to Ousubetz, a small fishing village.

The volcanic conglomerate of this region extends some distance inland, and consists almost entirely of more or less rounded fragments of black lava filled with green-coated cells.

August 22d. Leaving the sea we made a short excursion up the bed of a creek, the Kaiyanobetz. About one mile from the shore a gray sandstone was found exposed for a short distance beneath the volcanic conglomerate, and about one mile and a half further we found in the bed of a rivulet the following strata, the order reading from younger to older.[1]

1. Fine-grained argillaceous rock with fossil plants.
2. Coarse sandstone.
3. Clay shale with *Equisetaceæ.*
4. Coarse sandstone.
5. Three seams of bituminous coal alternating with thin beds of clay, the principal seam having about four feet of good coal.

The strike of these beds was N. 30° E., the dip being 50° to N. 60° W.

In a neighboring ravine a white silicious rock was observed, apparently older than the coal, and made up of minute layers, the whole being hard, and having somewhat the appearance of a semi-opal.

[1] Except a small specimen of coal which was brought away by one of the Japanese officers, all the collections from this region were lost in the wreck mentioned above.

Retracing our steps to Ousubetz we embarked in a boat propelled by eight oarsmen, four scullers, and a large sail, and soon reached Iwanai.

August 25th. Leaving Iwanai we went by boat to Isoya, passing close under the rocky cliffs of the Raiden. The northern part of this mountain is formed of the volcanic tufa-conglomerate covered by a great bed, or perhaps several flows, of lava, often exhibiting columnar structure. In places beds of lava seemed to be interstratified with the conglomerate.

At about half the distance between the northern and southern sides of this highland, a large amphitheatre or crateriform valley opens towards the sea. South of this the cliffs, less high, consist of the conglomerate, and in the perpendicular walls are visible many small but regular dykes with transverse columnar structure, and in places dislocated by faults. The conglomerate strata have a considerable southwesterly dip, and as we approach the southern flank of the Raiden, near the village of Hamajimé, they disappear under the sea. Overlying this formation and forming the mountain above, is a gray volcanic rock, possessing a tabular structure, which gives it often a stratiform appearance near the bottom, but in the upper half of its thickness the plates curve irregularly upwards, presenting their edges towards the upper surface of the bed.

This mountain is a high, flat ridge, running nearly east and west, between the valleys of the Shiribetz and the Shiribuka rivers, and on it is the Iwaou nobori, and at least one more volcano.

August 27th. Leaving Isoya, we rode around the head of Odaszu bay to Sutzu. On this side of the bay we met again terraces of conglomerate, covered with loose sand and gravel, corresponding to those mentioned as occurring on the opposite side.

Before reaching Sutzu the conglomerate formation was found to be succeeded, for a short distance, by a gray eruptive rock, apparently a trachytic porphyry. The conglomerate in this region consists, almost entirely, of rounded fragments of a compact black rock, almost a pitchstone, containing crystals of white triclinic felspar.

August 28th. Leaving Sutzu we rode westward, over the lower of the two terraces that rise between the sea and the hills. The highlands are wooded with small trees, but on the terraces there is generally only a heavy growth of weeds and joint-grass, often from six to ten feet high. Leaving the sea-shore, we crossed the promontory to its western flank, travelling over the conglomerate, upon which was seen a loose deposit of sand and gravel closely resembling the auriferous deposit of Kunnui. In one place I observed an outcrop of the argillaceous rock, with the peculiar vermiform fossil, seen at Kunnui, Washinoki, etc.

At Achase the tufa-conglomerate dips inland, and beneath it there is an apparently conformable bed of fine-grained, brown sandstone, easily scratched with the knife, and seemingly of the same origin as the conglomerate.

A few miles further southward we reached Shimakomaki. Here the semi-vitreous character of the pebbles that compose the conglomerate is better developed than usual, although a black amorphous base was found to be generally prevalent, in these fragments, in the tufa-conglomerates of the west coast. Here the base of the rock is jet black, opaque, with the lustre of pitch, and imperfect conchoidal

fracture. Fragments break off with a very hackly surface. The structure varies from slightly cellular to scoriaceous, the cells being lined with a light greenish or bluish film. It contains thin crystals of white, glassy felspar, the number of which seems to be in an inverse ratio to that of the cells. The felspar is, at least in part, a triclinic variety.

The Tomari creek, which enters the sea near Shimakomaki, brings down among its rubble, diorite, granular limestone containing nephrite, clay schist, and varieties of quartz and jasper. This stream rises in the hills that have furnished, in part at least, the auriferous gravels of Kunnui, and it is probable that similar deposits occur also in the valley of the Tomari.

August 29th. Embarking in a large boat we sailed close under the lofty cliffs of a grandly picturesque, but dangerous coast, as far as Setanai.

The volcanic conglomerate exists as the principal formation of the coast, between Shimakomaki and Setanai. At Cape Shiraita the thickness of the conglomerate, above the sea, is between 100 and 200 feet; above this is a bed, perhaps 150 feet thick, apparently of a looser material, with many white fragments scattered through it; and, finally, covering this, for a distance of one or two miles, is a bed of lava, 150 to 200 feet thick.

From this point to Cape Moteta the cliffs are entirely of the volcanic conglomerate, of which a lower bed is sometimes visible, with white fragments, those of the upper beds being dark brown or black.

At Cape Moteta the volcanic conglomerate, occupying the lower part of the cliffs to the height of between 100 and 200 feet above the sea, is covered by a thick bed of columnar lava. Near this point a broad dyke rises through the conglomerate to the overlying lava bed, but it was impossible to determine, at a distance, the relative ages of the latter and the dyke.

Numerous dykes traverse the conglomerate between Cape Moteta and Setanai. At Abura the latter approaches sandstone in texture; at one place it was seen to pass abruptly into a white deposit, probaby a pumiceous tufa.

South of Abura the conglomerate is covered by a lava bed, and this by white, apparently tufaceous, strata.

Several miles north of Setanai a thick bed of columnar lava is visible, high up the face of the cliff, lying between two members of the neptuno-volcanic formation, and dipping gently toward the south. Before reaching Setanai a thick flow of lava, beautifully columnar and probably the continuation of the bed just mentioned, occupies the lower half or more of the cliff, while needles of the same rock rising high out of the sea form picturesque islands.

This rock is a dark brown, much weathered, cellular lava. The cells are coated with a soft, brittle mineral, dark green in the fracture, and light bluish-green on the surface; and being flattened and parallel, with their planes at right angles to the axes of the columns, they give to the rock a slaty structure. Overlying this lava bed there are strata of tufa-conglomerate, made up mostly of fragments of cellular and scoriaceous volcanic products.

Just south of Setanai the Toshibetz—here several hundred feet broad—the river, on which lie the gold washings of Kunnui, empties into the sea—its valley, here

several miles broad, being the first break, of any size, in the uninterrupted line of cliffs south of the Bay of Odaszu.

August 30th. Continuing our journey southward we followed the beach, separated here by high sand hills from the flats of the Toshibetz, till Futoro.

Just before reaching this village we left the valley and came under a bluff of trachytic or phonolithic lava, with a tendency to slaty structure. It has a light gray base, with semi-vitreous lustre, and is cellular—the cavities being very irregular in shape and lined with a grayish-blue botryoidal mineral. It contains numerous crystals of a glassy triclinic felspar.

At Futoro the volcanic conglomerate reappears as a red and brown tufa, with fragments of the lava just described and other varieties that show a regular transition from this lava into a black amorphous kind closely resembling that mentioned as forming dykes at Isoya. The strata of this neptuno-volcanic formation strike nearly N. and dip to E. about 20°, and the cleavage planes of the lava bed described above dip in the same direction. This lava flow seems to be at least 250 or 300 feet thick. Just south of Futoro the contact between the lava and conglomerate was observed. The former rock at a little distance from the contact was found to be fresh, generally free from cells, and had a light gray compact base, abounding in crystals of triclinic, glassy felspar, with here and there a crystal of hornblende. Its appearance reminded me strongly of some non-quartziferous felsitic porphyries. Near the contact it became more earthy, and assumed the appearance of the base of the conglomerate, from which it was here distinguishable only by the crystals of felspar. The whole appearance of the contact seemed to indicate that the lava had flowed over the surface of the older deposit before this had become compacted.

August 31st. From Futoro we went by boat to Oöuta. Not far from Futoro the volcanic formations were seen to rest upon a granite or syenite, which, a little further south, abuts, with a vertical line of contact, against a compact black, aphanitic rock. This last was seen, in the face of a rock rising from the sea, to be traversed by veins of granite which, just south of this, was found to form the high cliffs till near Oöuta.

At Nichinbe, about three miles north of Oöuta, the prevailing rock was found to be a very beautiful syenitic granite, composed of greenish-white triclinic felspar, brilliant hornblende, black mica, and quartz. It is traversed by a dyke of a green, micro-crystalline rock, containing felspar and hornblende.

At Oöuta there is an extensive development of metamorphic rocks, consisting of a fine-grained granulite of even texture, and a conglomerate-breccia of argillaceous rocks. The only traces of a trend observable was in the vertical plane of contact between these two rocks, and this lay N. and S. South of Oöuta syenite reappears, and is shown to be younger than the granulite by the numerous fragments it incloses of the last-mentioned rock.

The granulite is cut by dykes of an aphanitic rock similar to that observed south of Futoro, and which we have seen to be traversed by veins of granite. Finally, the conglomerate-breccia incloses fragments of amygdaloid resembling a variety found in the auriferous gravel of Kunnui, and containing nodules of chalcedony surrounded by a soft green mineral resembling delessite.

The relative ages of the metamorphic and intrusive rocks of this region appear to be as follows, reading from younger to older:—

1. Greenstone of Nichinbe; dyke in syenitic granite.
2. Syenitic granite.
3. Aphanitic rock.
4. Metamorphic conglomerate and granulite of Oöuta.
5. Amygdaloid.

September 1st. Continuing the journey by boat we reached Kudo—the syenitic granite forming high hills along the sea as far as Ouenkoto, near Kudo.

At Kudo other metamorphic strata were observed, consisting of black and rose-colored quartz-schist, clay slate in thin beds, and a dark brown, micro-crystalline rock, apparently felspar and hornblende. These strata are folded and refolded, and the stratification being well preserved, they presented the finest example of plication I had ever seen. The general trend of the folding seemed to be about E., but there was too much irregularity in this respect to make sure of the direction; further south the trend appeared more regularly N. W. and the dip N. E.

The beds are traversed by a dyke of a porphyritic rock containing crystals of green and greenish-white triclinic felspar and of hornblende, in a grayish purple base.

A cold spring of chalybeate and carbonated water rises on the beach from the quartzite.

September 2d. Riding along the sea-shore, a few miles, we reached the penal establishment of Ousubetz, at the mouth of a creek of the same name.

Ascending this stream, which is a wild mountain torrent contained, near the sea, between cliffs of the volcanic conglomerate, we came upon an amygdaloidal rock, and beyond this a chloritic granite containing, besides quartz and chlorite, white orthoclase and a light green triclinic felspar. In this granite there is a broad belt, apparently a dyke, of a claystone-porphyry, a yellowish rock with a rough, earthy base free from visible quartz, and from which the crystals of felspar have disappeared, leaving only their cavities. From this porphyry issue several springs, which showed in different instances temperatures of 55°, 58°, and $58\frac{1}{2}$° C.

These springs have formed deposits, of carbonate of lime and brown oxide of iron, which are more or less cavernous, and are the abode of a great number of snakes, which, attracted by the perpetual warmth, and being respected by the natives as the deities of the place, live unharmed. The cast-off skins of these reptiles flutter, like streamers, from every hole and neighboring bush.

Beyond the chloritic granite we found again the amygdaloid which, under various forms, extended as far inland as our excursion continued, about one mile beyond the chloritic granite.

In one of the side ravines a bluish-white, highly silicious rock, with conchoidal fracture and impregnated with minute cubes of iron pyrites, was observed in contact with the amygdaloidal rock.

This amygdaloid is very variable in character, in places brecciated, in others massive—the base being generally dark reddish-brown, and containing nodules of calcite and a green, soft clayey mineral, with here and there one of quartz. Frag-

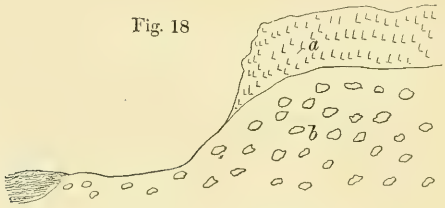
ments of a green serpentinoidal rock, which seemed to be a variety of the amygdaloid, occur in the creek.

September 4th. Descending to the sea we rode southward along the shore, under cliffs of the volcanic conglomerate, as far as the large village of Kumaishi.

September 5th. Leaving Kumaishi we followed the beach southward. From the village south the shore bluff is formed by a vertical cliff of white pumice-tufa, sufficiently hard to permit the making of steps in it. It is in thick beds having a southerly dip. South of Hiratanai this pumice-tufa is covered by the usual tufa-conglomerate.

A short distance east of Hiratanai a flow of amorphous lava, resembling that which occurs in fragments in the conglomerate of Isoya and Futoro, flows over the face of the bluff—the erosion of the conglomerate having progressed to nearly its present condition before the flow. A conical hill with a crateriform depression, lying several miles inland, was observed from the beach, and was possibly the source of the stream.

Fig. 18



a. Lava flow. *b.* Tufa-conglomerate.

Beyond this point, as far as Tomarigawa, another bed of pumice-tufa, overlying the conglomerate, forms the bluff-rock and the skeleton of the terraces that extend several miles inland.

At Tomarigawa we left the sea-shore and entered the mountains, and ascending to the watershed between the Japan sea and Volcano bay, we descended the eastern slope to the mines of Yurup.

Our road, during this distance, lay, all the way, over the volcanic tufa-conglomerate formation, which extends entirely across this part of the island, and forms the ridge at a height of perhaps 2,000 feet.

This deposit is cut up by deep valleys with steep sides. In these I noticed outcrops, beneath the conglomerate, of granite, two or three miles from the sea, and, further eastward, of the argillaceous rock with vermiform fossils already mentioned several times.

The lead mines of Yurup are in the valley system of the river of the same name. Here a widely extended erosion has removed the volcanic conglomerate, for a considerable distance, exposing a very extensive development of a black metamorphosed argillite, which was found to contain the vermiform fossils so often mentioned in the previous pages. The strata are tilted up, often almost vertical, and are frequently connected with broad bands, apparently dykes, of greenstone. The lead-bearing veins occur in both these rocks. The vein-mass consists of quartz, carbonate of manganese, calcite, and, in one vein, crystals of barytes. Besides these minerals the galena is associated with zincblende, and pyrites of iron and copper.

The veins vary from two to eighteen inches in thickness, being more regular in

the greenstone where, also, the gangue is chiefly quartz, and often existing as a zone, several feet broad, of parallel threads, in the argillaceous rock.

The mines have been worked several years and a considerable area explored, but like those at Ichinowatari they are very poor—the highest production ever attained being about four tons per month, and at the time of my visit it was only about one and three-quarter tons.

The processes of separation and smelting are the same as at Ichinowatari. The laborers are furnished, at the expense of the mine, with rice and *miso*, a vegetable substance used for soup. I have added a schedule of the daily expenses, more as a curiosity, and as illustrating the cost of labor, than for any other reason.

Daily Expenses of the Yurup Lead Mines.

Accountant clerk	$ 05
Head miner	07
Twenty-five miners, at 5 cts.	1 25
Eighteen coolies, at 4 cts.	72
Thirteen women ore dressers and washers, at 2 to 6 cents.	45
Daily consumption of iron	12
" " steel	04
" " mats and ropes	06
Total	$2 76

The working time is eight hours daily. The miners receive tasks, for all work over which they are paid extra. The task when working in the hardest rock, here a greenstone, is $\frac{3}{10}$ of one foot in five days, per man. In very soft rock five feet in five days, per man. The average is about one and one-half feet. The above measures refer to galleries five feet high and three broad. The miners are required to hew the walls as smoothly, and square the angles as accurately as was the custom in Germany before the use of gunpowder.

A woman's daily task is to pulverize about 160 pounds of ore.

One thousand pounds of roughly-sorted ore yields 67 pounds of *schlich*, from which 45 pounds of metallic lead are obtained.

The charcoal for smelting is produced in vaulted furnaces, which receive daily 64 cubic feet of split wood.

Both cold and warm chalybeate springs rise in the metamorphic argillite; the warm one, having the temperature of 46° C., is used in winter for washing the ore.

At this place we introduced the use of gunpowder in mining—its application to that purpose being entirely unknown throughout Eastern Asia. We met with the same objection here that was used, centuries ago, against its introduction into the German mines, the fear that the mountain would fall in. One blast, however, allayed this fear, and the miners adopted it enthusiastically thenceforth.

September 11th. Leaving Yurup we descended the valley to the sea. At the distance of about one mile from the mines we came again to the volcanic conglomerate. This formation is here similar in character to that seen between the Japan sea and the mines, but differs from that generally met with along the seashore. It has undergone so much alteration that it is often difficult to draw the line between the inclosing mass and the fragments. These latter are of a dark,

cellular rock with amorphous base, containing abundant crystals of hornblende and felspar. The cementing material is a more or less yellowish mineral, with the lustre of wax, and easily scratched with the knife. This mass also abounds in crystals of hornblende and felspar, and is cellular in the same manner as the inclosed fragments. Specimens show a transition from one to the other, and this is especially observable around the cells in the fragments. The general color of the rock is dirty yellow. If this be not a true palagonite tufa it must be closely related to it.

The strata of this formation dip gently, on the western slope, towards the Japan sea, and on the eastern slope, towards Volcano bay. They consist of two principal members, the lower, a fine-grained, soft tufa with black mica and fragments of nearly decomposed pumice; and the palagonite-tufa, if I may call it such, as the upper member.

At about half way between the mines and the sea we came again upon the argillaceous rock of the mines, containing the same characteristic fossil, but unmetamorphosed, and presenting itself as a soft gray argillaceous shale.

At the village of Yurup, on Volcano bay, we came into the road followed in going north, and completed the circuit of this itinerary.

Without attempting, in the absence of necessary data, to determine more closely the ages of the rocks referred to in the preceding pages, they may be generally classed as follows:—

I. Older metamorphic.

II. Pluto-neptunian.

III. Recent, including the marine terrace deposits.

IV. Eruptive, of all ages.

The first of these divisions contains all the sedimentary rocks that were observed to be older than the volcanic tufa-conglomerate formation. They are rocks that vary widely in character, and perhaps as widely in age. Forming the skeleton, of at least the southern part of Yesso, they are almost everywhere concealed by the younger deposits.

The most highly metamorphosed and perhaps the oldest strata observed are the granulite and conglomerate-breccia beds of Oöuta, on the west coast. These last are made up of older argillaceous and amygdaloidal rocks, but are also older than three varieties of eruptive rocks—aphanitic trap, syenitic granite, and a greenstone trap, apparently diorite.

The greatest part of the southeast peninsula, lying between Volcano bay and the Straits of Tsungara, is formed of fissile clay slates with subordinated beds of sandstone and conglomerates, the uplift trending nearly as the peninsula, about N. W. by W. These strata are traversed by frequent dykes of the characteristic white quartziferous porphyry, and varieties of greenstone, the latter being younger than the porphyry.

At Wosatzube, on the northern side of the peninsula, there are beds of silicious schist, having also a northwesterly trend, and strata of a similar character occur at Kudo, on the west coast, associated with subordinated clay slate and beds of a

hornblende-felspar rock. Here also the mean trend of the highly contorted beds is between W. and N.

The remaining older rocks of this part of the island belong to the Ichinowatari series, and the argillite beds containing the obscure vermiform fossil, so often mentioned. The Ichinowatari series are black and gray metamorphosed argillaceous rocks, associated with older or younger shale containing calamites of unknown age, and with greenstone; and they are characterized by metalliferous veins occurring at least in both the argillaceous rocks and in the greenstone.

The argillite beds we find at many points, throughout the region included in the above itineraries, occurring in places either as a compact gray rock or as a shale, while at Yurup it is metamorphosed to a compact black rock, tilted almost to perpendicularity. Between Tomarigawa, on the west coast, and Yurup, on Volcano bay, it is found, excepting in one locality, to be the predominating rock wherever the ravines have cut through to the bottom of the volcanic tufa-conglomerate strata. The rocks in question have, in common with the Ichinowatari series, their argillaceous character, their association with dykes and great masses of greenstone and an identity of character in the metalliferous veins of the two localities, both as regards the association of minerals in these and also as regards some peculiarities in the condition of the greenstone near these veins.

Finally we have seen, beyond Iwanai, near Ousubetz (north), a coal-bearing series of more or less metamorphosed rocks, containing fossil *Equiseta.*

We find, in the auriferous gravel of Kunnui, representatives of another class of metamorphic rocks in the chloritic and micaceous schists, etc., which are probably the source of the gold, and evidently exist *in sitû* in the ridge between that place and the Japan sea.

The enumerated strata form, so far as my observation extended, the skeleton of Southern Yesso. The local strike of the coal-bearing rocks of the Ousubetz (north) is N. 30° E., being nearly at right angles to the N. W. trend of the peninsula on which they occur. All the other beds of the older rocks seem to have been affected chiefly by an uplift trending between N. and W., and to which that portion of the island lying between Esan volcano and the mouth of the Toshibetz, on the west coast, appears to owe its direction.

We come now to the pluto-neptunian beds, consisting of great masses, more or less stratified, of volcanic products in the form of tufas, sandstones, and coarser conglomerates and breccias.

This, by far the predominating formation, forms almost everywhere sloping plains or terraces between the mountains and the sea-shore, and extends, at least in places, entirely over the watersheds between Volcano bay and the Japan sea, forming peaks, as the Obokodake, several thousand feet high.

The petrographical character of these beds is very different, not only in their vertical, but also in their horizontal development. Along the west coast we find thick beds of a white pumice-tufa associated with conglomerates made up of fragments of a black compact rock, almost a pitchstone. Along the road from Tomarigawa to Volcano bay the lowest beds observed were of a more clayey pumiceous tufa, and above these an immense development of a scoriaceous conglomerate.

breccia, altered in great part to a wacke and strongly resembling palagonite-tufa. Bordering the eastern end of the southeastern peninsula, we have seen the representative beds of this formation, but differing from those of the west coast in that the inclosed fragments have more the character of quartziferous trachytic porphyry, thus approaching closely in character to the wall rock of the Esan crater and its recent *ejecta*, as also to the rock of Hakodade peak.

The only traces of fossils observed in this formation, were some fragments of the spines of an Echinoderm found near Washinoki.

The presence of these deposits over so large an area, and the fact that they always contain beds of coarse material, points to a corresponding range of volcanic activity. The same is indicated in the numerous lava flows and dykes that are intimately associated with these beds.

They are probably of submarine origin, and since their formation the island has undergone many changes of level. A large part of Southern Yesso was under water during the deposition of these deposits; it seems to have been gradually elevated and submitted to littoral erosion, forming the different terraces, and then to have been partially submerged to receive the recent terrace clay deposits.

This recent terrace deposit exists as beds of clay, almost exclusively, along the southern slope of the southeastern peninsula, and bordering the western shore of Volcano bay, and in depressions inland from this, as in the valley of the Toshibetz. Along the west coast where the depth of water is great, and the coast precipitous, this deposit rarely exists as clay, and then only bordering deep indentations like the Bay of Odaszu; but it is perhaps partially represented by the gravelly covering of the volcanic conglomerate terraces. As has been already stated, this terrace-clay deposit abounds in the remains of recent Mollusks.

After the elevation of these recent terraces, and after the action of an extensive erosion, there were formed the auriferous gravels of Kunnui, and finally, more recent and still progressing, subaërial deposits, as the volcanic-ash beds around Comangadake.

Very little is known of the physical character of the rest of Yesso. Volcanic cones, extinct and active, seem to exist throughout the island. Coal occurs at several points on the east coast, and several ammonites and a piece of obsidian were shown to me by the Governor of Yesso, as coming from the Monbetz creek, on the northern coast.

The island receives an additional interest from being a point of intersection of three lines of upheaval, and evidently owes its remarkable shape to this fact.

The first of these lines is represented by the northwesterly trend, of that portion of the island extending from Esan volcano to the mouth of the Toshibetz, and this is also the trend of the uplifted metamorphic strata; indeed the southeastern peninsula seems to be an anticlinal axis, the dip of the beds being on both sides, along the coast, toward the sea. This is also the trend of the peninsula south of Strogonoff bay, and of the northern coast line.

The second line is that extending from the headland of Matzmai, northeast through the longer axis of the island and of the Kurile chain to Kamschatka. This determines also the northeasterly course of the eastern coast line.

The third line is that of the island of Sagalin (Krafto), which, trending due north and south, would seem to determine the N. S. course of the western coast line of Yesso, and the N. S. trend of Nippon from its northern point to the Bay of Yedo.

I have already referred the N. E. line of uplift to the Sinian system of elevation, in a previous chapter; the N. W. trend affecting, as it does, the oldest metamorphic rocks, is perhaps older, and the N. S. trend younger.

Neighborhood of Nagasaki, on the West Coast of the Island of Kiusiu.

This port is at the head of a long narrow inlet, or *fiord*, which has nearly a N. E., S. W. trend, and lies between long ridges, the peaks of which rise to between 1,000 and 2,000 feet above the sea. The skeleton rocks of these hills are metamorphic strata. These were mica schist dipping vertically, in both the ridges where they were examined, northwest and southeast from the city, and argillaceous and talco-argillaceous schists, with some limestone, where the eastern ridge was seen near its southern end, opposite the island of Kabasima. On this island the trend of the strata is nearly N., S., and they are traversed by a broad belt of granite bearing fragments of the schists near the planes of contact. On the island Amaksa, a few miles further east, crystalline, white limestone, and a fine sandstone are quarried.

The greater part of the country, in the neighborhood of Nagasaki, is covered, to the summits of the highest hills, with an extensive pluto-neptunian deposit, resembling in general character the volcanic tufa-conglomerate of Yesso.

In places along the eastern side of the bay, and on the islands at its mouth, the rocks of a coal-bearing formation are exposed. Of these only a coarse, hard sandstone, with threads of coal was seen, as it was not permitted to foreigners to land at any of these localities. The position of these beds, however, is such as to make it probable, that the rocks of this coal basin rest immediately, and nonconformably, on the metamorphic strata before mentioned.

In the terraces which in places fringe this coast, we have again evidence of oscillations in level, since the beginning of the volcanic epoch. The terraces are very tufaceous, and seem to be of more recent deposition than the conglomerate that covers the higher hills.

Bay of Yedo.

Nearly all the country included within the treaty limits, or radius of twenty-five miles from Yokohama, which area alone is accessible to foreigners, is of recent formation. A bluff, from 60 to 100 feet high, of bluish clay containing recent shells, and fragments of pumice, with an upper stratum of more gravelly character, faces the bay. From the summit of this bluff a plain of the same deposit extends westward, about twenty miles, rising gently, till the mountains of Oyama. I was not permitted to ascend these mountains, but from the gravels of the streams descending from them I judged them to be metamorphic. The fragments seen were of diorite, gabbro, and serpentine.

South of Yokohama the ridge of the peninsula of Sagami also furnishes fragments of serpentine. The western side of the peninsula, as well as the island of Enosima, are of a firm, fine-grained gray sandstone and conglomerate, in apparently horizontal strata.

Previous to the elevation of the recent beds, the peninsula of Sagami, and probably also the highland east of the Bay of Yedo, were islands.

The existence of these recent marine terraces along the Japanese coast, from Yesso to Kiusiu, and of similar deposits on the China coast, as at Chifu and along the western edge of the great delta plain, point to widely extended changes, in recent times, in the relative position of land and water. A careful study of their characters, as regards the organisms they contain—a study that should include the recent deposits of the Amur system,[1] and perhaps also those of the Manchurian rivers—would probably throw much light on the age of the Gobi desert deposits, and through this on some of the most important questions of quaternary and younger tertiary geology.

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[1] M. Schmidt observed, almost everywhere on the Amur, between Strelka and Blahowestschensk, terraces of fresh-water tertiary rising nearly 200 feet above the river.—*Peterman's Mittheilungen*, 1861, p. 315.

CHAPTER X.

MINERAL PRODUCTIONS OF CHINA.

THE following list of minerals, and their localities, is compiled from Chinese geographical works, the Tatsingitungchi having furnished the greater part, though for the sake of completeness, the special geographies of the different provinces, and often those of departments, were searched.

The compilation involved the examination, by the author's Chinese secretary, of over one thousand volumes.

Only a portion of the list compiled can be made available for publication owing to our inability to identify the Chinese names for a large proportion of the useful minerals.

The orthography adopted by Dr. S. W. Williams, for Chinese geographical names, is followed in the list, where the subdivision of the country into provinces, departments (Fu), and districts (Chau, Hien, or Ting), is also observed.

List of Localities of Useful Minerals in China.[1]

IRON.

PROVINCE OF CHIHLI.

SHUNTIEN (Fu) or PEKING. At TSUNHWA (chau). WANGPING (hien) at Chingshui near Chaitang. At Tiekung Mt. 30 li E. of MIYUN (hien).

PAUTING (Fu). In MWANCHING (hien).

SIUENHWA (Fu). In LUNGMUN (hien) lodestone.

YUNGPING (Fu). At Mang Mt. 15 li N. E. of TSIENNGAN (hien). At Mt. Tsz' 15 li W. of Lulung (hien), with gold and silver ores.

SHUNTEH (Fu). At Mt. Hai 40 li W. of SHAHO (hien.)

KWANGPING (Fu). Lodestone at Tsz' (chau).

PROVINCE OF SHANSI.

TAIYUEN (Fu). In TAIYUEN (hien) and YUTSE (hien).

PINGYANG (Fu). In KIUHYU (hien). YUTSUNG (hien). YOYANG (hien). KIH (chau). HIANGNING (hien)

PUCHAU (Fu). Hien not indicated.

KIAI (chau). In NGANI (hien).

KIANG (chau). At Mt Kiang 20 W. of KIANG (hien).

LUNGAN (Fu). Hien not indicated.

FANCHAU (Fu). At Siyen Mt. in HIAUNI (hien).

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[1] Localities producing coal, lime, alum, salt, and gold, are tabulated on pages 56–61.

TSEHCHAU (Fu). In YANGCHING (hien).
TATUNG (Fu). In HWAITSUNG (hien).
PINGTING (chau). Hien not indicated.

PROVINCE OF SHENSI.

SINGAN (Fu). Hien not indicated.
SHANG (chau). 180 li N. E. of the city at Mt. Tiling.
PIN (chau). Hien not indicated.
FUNGTSIANG (Fu). In LUNG (chau) and MEI (hien).
HANCHUNG (Fu). In TSUNGKU (hien). At Lotsung Mt. N. W. of SIAYANG (hien). At Tie Mt. 5 li N. of MIEN (hien).
FU (chau). In CHUNGPU (hien) and IKIUN (hien).

PROVINCE OF KANSUH.

PINGLIANG (Fu). In PINGLIANG (hien) and HWATING (hien).
KUNGCHANG (Fu). At Te'yang Mt. 120 S. of NINGYUEN (hien). At Ningkwei Mt. 30 li S. of Ningyuen (hien), with silver and copper ores.
TSIN (chau). In TSINGNGAN (hien) and HWUI (hien).
KINGYANG (Fu). At Mt. Hungling 18 li N. of NGANHWA (hien).
NINGHIA (Fu). Hien not indicated.

PROVINCE OF SHANTUNG.

TSINAN (Fu). In CHICHUEN (hien). At Mt. Chang 50 li S. E. of SINCHING (hien).
TAINGAN (Fu). In LAIWU (hien); S. E. 13 li at Mt. Tashï, and N. W. 3 li at Mt. Kung.
YENCHAU (Fu). In YIH (hien).
ICHAU (Fu). At Mt. Chipau 100 li N. of KÜ (chau) in vicinity of gold, silver, copper, lead, and tin ores.
TSINGCHAU (Fu). A Mt. Tie 90 li from YIHTE (hien). In KAUYUEN (hien) and LONGAN (hien). At Mt. Chang in LINGTSE (hien). At Mt. Sung 60 li S.W. of LINKÜ (hien) in the vicinity of silver, lead, copper, tin, and cinnabar ores and gold washings.
TUNGCHAU (Fu). In PUNGLAI (hien).

PROVINCE OF KIANGSUH.

KIANGNING (Fu) or NANKING. At Tsz Mt. in KIUYUNG (hien), with copper ores. Lodestone at Mt. Yen in LUHHOH (hien).
CHINKIANG (Fu). 30 li S. W. of LIYANG (hien).
HWAINGAN (Fu). In YENCHING (hien).
SÜCHAU (Fu). At Mt. Pema 90 li N. E. of TUNGSAN (hien).

PROVINCE OF NGANHWUI.

NGANKING (Fu). Hien not indicated.
TAIPING (Fu). Steel works at Tekang in FANCHANG (hien).

PROVINCE OF HONAN.

HONAN (Fu). In the hiens, KUNG, NIYANG, TUNGFUNG, SINGAN, and SUNG
NANYANG (Fu). In the hiens, NANYANG and NEYANG.
KAIFUNG (Fu). In YU (chau).
CHANGTEH (Fu). In SHEH (hien).
JU (chau). Hien not given.

PROVINCE OF HUPEH.

WUCHANG (Fu). In KIANGHIA (hien) and WUCHANG (hien). At Mt. Hwuilu E. of TAYÉ (hien). At Mt. Tsz'hu 50 li N. E of TAYÉ (hien) lodestone. At Hwangko Mt. 2 li W. of HINGKWOH (chau), in vicinity of silver ores.

HWANGCHAU (Fu). At Mt. Kung 40 li W. of MACHING (hien). At Mt. Kung 15 li S. E. of HWANGMEI (hien).

PROVINCE OF SZ'CHUEN.

CHINGTU (Fu). In TSINGTSING (hien).
TSZ' (chau). Hien not indicated.
MIEN (chau). Hien not indicated.
NINGYUEN (Fu). In HWUILI (chau), MIENNING (hien), and YENYUEN (hien).
PAUNING (Fu). In KWANGYUEN (hien).
SHINGKING (Fu). Hien not indicated.
CHUNGKING (Fu). At Mt. Tie 80 li S. E. of YUNGTSANG (hien). In HOH (chau). In TUNGLIANG (hien).
CHUNG (chau). In FUNGTU (hien).
KWEICHAU (Fu). In WUSHAN (hien) and YUNYANG (hien).
SUITING (Fu). In KÜ (hien) and in TATSOH (hien).
LUNGNGAN (Fu). Hien not given.
TUNGCHUEN (Fu). In YENTING (hien) and SHÏHUNG (hien).
KIATING (Fu). 40 li N. of WEIYUEN (hien). 100 li N. of YUNG (hien).
KUNGCHAU (Fu). At Kusung Mt. 10 li S. of the city in vicinity of copper ore.

PROVINCE OF KIANGSI.

NANCHANG (Fu). In FUNGSIN (hien) and TSINHIEN (hien).
KWANGSIN (Fu). In YOHYANG (hien), YÜSHAN (hien), KWEICHI (hien), and SHANGTSAO (hien).
KANCHAU (Fu). At Tishan in WEITSANG (hien).
NANNGAN (Fu). In TAYÜ (hien).

PROVINCE OF HUNAN.

CHANGSHA (Fu). Hien not given.
SHINCHAU (Fu). Hien not given.
HANGCHAU (Fu). Hien not given.
YUNGCHAU (Fu). Hien not given.
YUNGSHUN (Fu). Hien not given.
PAUKING (Fu). Hien not given
CHANGTEH (Fu). Hien not given.
CHIN (chau). Hien not given.
TSING (chau). Hien not given.
LI (chau). Hien not given.
KWEIYANG (chau). Hien not given.
YOCHAU (Fu). Hien not given.

PROVINCE OF KWEICHAU.

SZ'CHAU (Fu). At Mt. Lungtang E. of the city, in vicinity of lead ores.
TUNGJIN (Fu). 100 li W. on Sungchi river, in vicinity of gold washings. 140 li W. in the Tichi river.
LIPING (Fu). Hien not indicated.
SHIHTSIEN (Fu). Hien not indicated.
TATING (Fu). In WEINING (chau).
SZ'NAN (Fu). In NGANHWA (hien).

PROVINCE OF CHEHKIANG.

KIAHING (Fu). In HAIYEN (hien).
TAICHAU (Fu). At Lungsu Mt. in NINGHAI (hien), in vicinity of copper ore.
YENCHAU (Fu). At Mt. Tie in KIENTE (hien).
WANCHAU (Fu). In PINGYANG (hien). In TISUNG (hien). In SUINGAN (hien).
CHUCHAU (Fu). In SIENPING (hien).

PROVINCE OF FUHKIEN.

FUHCHAU (Fu). In the hien FUHTSING and MING.
TSIENCHAU (Fu). In the hien TUNGNGAN and NGANCHI.
KIENNING (Fu). In the hien KIENNGAN, TSUNGHO, WUNING, and SUNGCHI.
YENPING (Fu). In the hien NANPING, YUKI, and TSIANGLOH.
TINGCHAU (Fu). In the hien HIANGHANG, NINGHWA, and TSANGTING.
CHANGCHAU (Fu). In LUNGCHI (hien).
FUNING (Fu). In NINGTEH (hien).
YUNGCHUN (chau). In TEHHWA (hien).

PROVINCE OF KWANGTUNG.

LIEN (chau). In YANGSHAN (hien).
SHAUCHAU (Fu). In UNGYUEN (hien).
SHAUKING (Fu). In hien YANGTSUNG, YANGKIANG, and SIUHING.
KIUNGCHAU (Fu). Lodestone, locality not given.
LOTING (chau). Excellent ore at Mt. Wutungtu in TUNGNGAN (hien).

PROVINCE OF KWANGSI.

LIUCHAU (Fu). In YUNG (hien).
PINGLOH (Fu). At Chingkang Mt. 120 li S. E. of Ho (hien). At Mt. Chaukang 45 li N. E. of Ho (hien).

PROVINCE OF YUNNAN.

YUNNAN (Fu). In KWUNGMING (hien) and YUNGMEN (hien).
LINGAN (Fu). In SINGO (hien) at Hungtonientsa, Sanhotsa, Liulungtsa, and Tsingtsa. In SHIH-PING (chau).
TSUHIUNG (Fu). At TSUYUTSUNG in TINGYUEN (hien). 50 li W. of TSUNGNAN (chau).
CHINKIANG (Fu). In SINGHIUNG (chau).
KIUHTSING (Fu). At Tseh Mt. in SIUENWEI (chau) in vicinity of copper ore. In NANYING (hien), and in the chau LOHLIANG, CHENYIH, MALUNG, and NANYING.
WUTING (chau). Iron ore and iron works at Tameti (tsang), Tsetse (tsang), Ineh (tsang), Loti (tsang), and Sanpu (tsang). Also in LUHKIUEN (hien) at Tsiehliu (tsang) and Tsutsu (tsang).
YUNGCHANG (Fu). Iron works at Aying.
TUNGCHUEN (Fu). At Mokwei and Tashuitang.
MUNGHWA (ting) In the mountains west of the city.
YUNGPEH (ting). Locality not indicated.

ORES OF COPPER, SILVER, LEAD, TIN, QUICKSILVER.

PROVINCE OF CHIHLI.

SHUNTIEN (Fu) or PEKING. Silver at Mt. Yinyen 15 li S. of MIYUN (hien). Silver at Sz'ling 100 li N. E. of MIYUN (hien).

YUNGPING (Fu). Silver 130 li N. W. of TSIENGAN (hien). Silver at Mt. Tsu 15 li W. of LULUNG (hien), in vicinity of gold and iron ores. Silver at Mt. Yühwang 90 li N. E. of FUNING (hien). Tin in TSIENNGAN (hien).

PAUTING (Fu). Copper.

SIUENHWA (Fu). Silver in YU (chau).

PROVINCE OF SHANSI.

PINGTING (chau). Copper in YU (hien).

TAI (chau). Blue and green carbonates of copper.

PINGYANG (Fu). Copper at Mt. Kiang 20 li S. W. of KIUHIU (hien).

KIAI (chau). Copper in twelve localities. Silver in NGANI (hien). In PINGLOH (hien) silver in several localities, copper in forty-eight localities, and tin at Mt. Ki 60 li N. E. of the city.

KIANG (chau). In YUENCHU (hien). Lead at Mt. Peh, and copper at Mt. Sanchuen 80 li N. of city. Copper in WUNGHI (hien).

LUNGAN (Fu). Copper in all the hien.

TSIN (chau). Tin in TSINYUEN (hien).

TSEH (chau). Copper and tin in YANGCHING (hien).

TATUNG (Fu). Copper. Malachite at Mt. Shïlieu 5 li E. of the city.

PROVINCE OF SHENSI.

SINGAN (Fu). Silver. Copper at Mt. TSUNGNAN 50 li South of city, in vicinity of jade and iron.

SHANG (chau). Cinnabar. In LOHNAN (hien), malachite at Mt. Yih 60 li E. of city. Silver and tin at Mt. To 90 li S. W.; copper 90 li S. E., and at Sihungnien 50 li S. E. of city.

HANCHUNG (Fu). Quicksilver and cinnabar at Mt. Sz'ni N. W. of LIAYANG (hien).

HINGNGAN (Fu). Blue and green carbonates of copper at Mt. CHINGLIEU 45 li E. of city. Cinnabar and quicksilver at Mt. Shuiyin 140 li N. E. of Sinyang (hien).

PROVINCE OF KANSUH.

PINGLIANG (Fu). Silver and copper in PINLIANG (hien). Silver and copper in HWATING (hien).

KUNGCHANG (Fu). Silver and copper at Mt. Ningkwei 30 li S. of NINGYUEN (hien).

KIAI (chau). Quicksilver. Silver at Yinyu 73 li N. W. of WAN (hien).

TSIN (chau). Silver at Mt. Tayang 50 li N. E. of TSINGNGAN (hien). Copper in TSINGNAN (hien). Silver at Mt. Sungkia 90 li N. E. of LIANGTANG (hien). Silver in TSINGSHUI (hien). In HWUI (hien) lead, and at Mt. Chichi, S. of city, cinnabar.

PROVINCE OF SHANTUNG.

TAINGAN (Fu). Copper at Mt. Yingliang 30 li N. of LAIWU (hien).

YENCHAU (Fu). Tin in YIH (hien). Copper at Mt. Koyeh 15 li S. E. of YIH (hien).

ICHAU (Fu). Lead in ISHUI (hien). Silver in vicinity of gold ores, at Mt. Pau 90 li S. W. of LANSHAN (hien). Silver, lead, copper, and tin, as well as gold and iron, at Mt. Chipau 100 li N. of KÜ (chau). In MUNGYING (hien), quicksilver at Mt. Hung 30 li N. of city; and silver at Mt. Leanghien 60 li N. W. of city.

TSINGCHAU (Fu). Silver, lead, copper, tin, quicksilver, as well as iron, and gold-sand, at Mt. Sung 60 li S. W. of LINKÜ (hien).

PROVINCE OF KIANGSUH.

KIANGNING (Fu). Copper at LISHUI (hien). Copper in vicinity of iron at Mt. Tsz in KIUYUNG (hien).

SUCHAU (Fu). Copper at Mt. Tung 80 li N. E. of TUNGSHAN (hien).

PROVINCE OF NGANHWUI.

NGANKING (Fu). Cinnabar in TAIHUSZ'.

HWUICHAU (Fu). Silver and lead.

NINGKWOH (Fu). Copper in all the hien.

PROVINCE OF HONAN.

HONAN (Fu). Lead in SUNG (hien), and tin at Mt. Lupan in the same hien.

NANYANG (Fu). Copper at Mt. Chihli in TSINGPING (hien). Tin in YÜ (chau).

CHANGTEH (Fu). Native copper. Tin in WUNGAN (hien).

JU (chau). Tin.

SHEN (chau). Tin in LUSHI (hien) and in LINGPAU (hien).

PROVINCE OF HUPEH.

WUCHANG (Fu). Silver at Mt. HWANGKO 2 li W. of HINGKWOH (chau) in vicinity of iron. Copper in KIANGHIA (hien). Copper in WUCHANG (hien). Copper at Mt. Peisuh 60 li N. of TAYÉ (hien). Tin at Mt. Sieh 5 li S. of FUNGTSUNG (hien).

NGANLOH (Fu). Malachite in TIENMUN (hien).

YUNYANG (Fu). Tin.

PROVINCE OF SZ'CHUEN.

CHINGTU (Fu). Copper in KIEN (chau), and in KINGTANG (hien).

MIEN (chau). Silver. Tin.

NINGYUEN (Fu). Silver at Mt. Miloh 200 li E. of HWUILI (chau). In HWUILI (chau) copper at Fénshuiling 100 li N. of city, and "white copper" (Petung), probably a complex ore, at Mt. Haichi 120 li S. of city. In the same chau green and blue carbonates of copper. "White copper in MIENNING (hien). Copper at Mt. Nan in SICHANG (hien). Silver at Mt. Kohsowa N. W. of YENYUEN (hien).

CHUNGKING (Fu). Copper. Cinnabar in KIKIANG (hien).

YUYANG (chau). Quicksilver and Cinnabar in PANGSHUI (hien).

KWEICHAU (Fu). Tin.

LUNGNGAN (Fu). Tin and Quicksilver.

TUNGCHUEN (Fu). Green and blue carbonates of copper. Copper at Mt. Komung 30 li N. W. CHUNKIANG (hien), also 24 li W. at Mt. Laiyung S., and at Mt. Tungkwei S. W. of the same hien.

KIATING (Fu). Copper at Mt. Tung 120 li S. W. of HUNGYA (hien).

KUNG (chau). Copper, in vicinity of iron, at Mt. Kusung 10 li S. of city.

LU (chau). Blue and green carbonates of copper.

YACHAU (Fu). Copper at Mt. Tung 30 li N. E. of YUNGKING (hien).

MAU (chau). Cinnabar.

PROVINCE OF KIANGSI.

NANCHANG (Fu). Copper at Mt. Si.

JAUCHAU (Fu). In FÉHING (hien), copper, and at Mt. Ying, silver.

KWANGSIN (Fu). Silver at YOYANG (hien) and YUSHAN (hien). Lead in TSIENSHAN (hien).

KIENCHANG (Fu). Silver in NANTSUNG (hien).

FUCHAU (Fu). Copper in LINGTSE (hien). In KINKI (hien) silver, and 120 li E. at Mt. Tung copper.

LINKIANG (Fu). Silver in SANKAU (hien). Copper in SINYÜ (hien)

KANCHAU (Fu). Copper in CHANGNIN (hien).

NANNGAN (Fu). Lead and tin in TSUNGNI (hien).

PROVINCE OF HUNAN.

CHANGSHA (Fu). Silver, copper, lead, tin, and quicksilver.
SHINCHAU (Fu). Cinnabar. Quicksilver on Luki river.
HANGCHAU (Fu). Silver, tin, quicksilver.
YUNGCHAU (Fu). Silver, tin.
YUENCHAU (Fu). Cinnabar and quicksilver in TSZ'KIANG (hien), FUNGHWANG (ting), YUNGSUI (ting), and WUKANG (chau).
PAUKING (Fu). Silver. Cinnabar in WUKANG (hien).
CHIN (chau). Copper, tin, lead, quicksilver, and cinnabar.
KWEIYANG (chau). Silver, copper, lead.
YOCHAU (Fu). Silver.

PROVINCE OF KWEICHAU.

KWEIYANG (Fu). Cinnabar and quicksilver in KAI (chau).
SZ'CHAU (Fu). Lead, in vicinity of iron, at Mt. Lungtang E. of the city. Cinnabar and quicksilver at the Sz'chi river.
TUNGJIN (Fu). Cinnabar and quicksilver at Mt. Tawan 3 li S. of city.
SHIHTSIEN (Fu). Cinnabar and quicksilver.
TATING (Fu). Copper in WEINING (chau).
TSUNI (Fu). Quicksilver and Cinnabar.
SZ'NAN (Fu). Cinnabar at Mt. Nitan 5 li S., at Mt. Ningtsing 30 li N. E., and 50 li N. E. of WUCHUEN (hien). Quicksilver at Moyu, Pangtsang, and Nientau, in WUCHUEN (hien).
HINGI (Fu). Quicksilver in vicinity of realgar, at Mt. Peinien. Cinnabar at LAMOTSANG.
TUYUN (Fu). Lead at Mt. Hianglu in CHINGPING (hien).

PROVINCE OF CHEHKIANG.

KIAHING (Fu). Copper at Mt. Tsang in HAIYEN (hien).
HUCHAU (Fu). Copper and tin in ANKI (hien). Copper in WUKANG (hien) and CHANGHING (hien).
NINGPO (Fu). Tin, in vicinity of gold, on Mt. Kehyu. Copper in FUNGHWA (hien).
SHAUHING (Fu). Copper at Soyachi. Tin at Mt. Tsoking. Quicksilver at Mt. Lungkien in YÜYAU (hien).
TAICHAU (Fu). Silver and lead at Mt. Tientai and Mt. Tsz'nien in TIENTAI (hien). Copper, in vicinity of iron, at Mt. Lungsu in NINGHAI (hien).
KÜCHAU (Fu). Silver ore, yielding $300 to the ton, at Mt. Yinkung in CHANGSHAN (hien). Copper at Mt. Tung in SINGAN (hien). Silver at Mt. Yinkung in SUINGAN (hien).
YENCHAU (Fu). In KIENTE (hien) copper in Mt. Tungkwei; and silver in Mt. Yin.
WANCHAU (Fu). In PINGYANG (hien) silver at Mt. Chauki, Mt. TSZ'YE, and Tientsingyang. Silver on the Chauchi river in TISUNG (hien).
CHUCHAU (Fu). Copper at Mt. Tung in LUNGTSIUEN (hien). Tin and lead in SUNGYANG (hien).

PROVINCE OF FUHKIEN.

KIENNING (Fu). Silver in the hien, KIENNGAN, KIENYANG, PUSUNG, and TSUNGHO. Copper in KIENYANG (hien).
YENPING (Fu). Copper in the hien, NANPING, SHA, and YUKI.
YUNGCHUN (chau). Lead in TATING (hien).
LUNGNGAN (chau). Lead in Santsingming and Tsiweitsz'kung.
TINGCHAU (Fu). Silver at Lungmuntsang in NINGHWA (hien). Silver at Wangpeitsang and Nganfungtsang in TSANGTING (hien). Tin at Hiangpau Mt. in TSANGTING (hien).

PROVINCE OF KWANGTUNG.

KWANGCHAU (Fu) or CANTON. Silver at Tashuikung in NANHAI (hien) and at Peyinkung in SINHWUI (hien).
LIENCHAU (Fu). Silver. Tin at Sangpuhia and Singtanghia in YANGSHAN (hien); in the same hien lead and cinnabar.

HWUICHAU (Fu). Tin of excellent quality in HOYUEN (hien) and YUNGNGAN (hien).
KIAYING (chau). Tin in SANLO (hien) and HINGNING (hien).
SHAUKING (Fu). Silver at Yinkung in KAUMING (hien).
KIUNGCHAU (Fu). Blue carbonate of copper. Silver at Litien in YAI (chau).

PROVINCE OF KWANGSI.

KWEILIN (Fu). Silver and Cinnabar.
LIUCHAU (Fu). Silver in SIANG (chau).
KINGYUEN (Fu). Silver at Mt. Mongin 35 li N. W. of HOCHI (chau). Tin at Kaufungkung 13 li W. and Singchaukung 2 li W. of HOCHI (chau). Cinnabar at Mt. Hi N. of Ishan (hien), and at Mt. Kusih in SZ'NGAN (hien).
SZ'NGAN (Fu). Lead in SHANGLING (hien).
PINGLOH (Fu). Silver in PINGLOH (hien). Silver and tin in FUCHUEN (hien). Silver at Taiping-yintsang in Ho (hien). Copper at Mt. Kü 35 li N. E. of Ho (hien). Tin at Tungyuyen and at Lungtsungyen N. of Ho (hien).
YUHLIN (chau). Cinnabar and quicksilver at Mt. Tungshi 15 li E. of PEHLIU (hien).
SINCHAU (Fu). Silver and lead in KWEI (hien).

PROVINCE OF YUNNAN.

YUNNAN (Fu). Copper in KWUNGMING (hien) and YUNGMEN (hien). Malachite in LIUTSZ' (hien), WUTING (hien), and LUFUNG (hien).
LINGAN (Fu). Copper and Tin in MUNGTSZ' (hien).
TSUHHIUNG (Fu). Silver in KWANGTUNG (hien), and at Soyangtsang and Malungtsang in NGAN (chau), and with lead at Yuntsungtsang in TSUHHIUNG (hien).
CHINGKIANG (Fu). Copper in Lunan (chau).
KWANGSI (chau). Silver and lead at Mt. Peting. Copper at Mt. Chung. Tin at Mt. Shïpau.
KIUHTSING (Fu). Silver and lead at Mt. Yang W. of SIUENWEI (chau). Copper in PINGI (hien).
WUTING (chau). Silver in Sutsuweitsang. Copper at Pauhung and Olo. Lead at Mt. Kauyin.
PU'RH (Fu). Silver, lead, and copper at Pema, Kanku, and Mantau in SIHMA (ting). Copper of best quality at Tsilitutsz'.
YUNGCHANG (Fu). Silver at Mingkwang and Aying. Copper and tin at TANGYUEH (chau).
TÜNGCHUEN (Fu). Silver in WEITSZ' (hien). Mines of Petung ("white copper") at Tangtangtsang and Talütsang.
CHAUTUNG (Fu). Silver at Lutientsang and Lomatsang, at Tungputsang in CHINHIUNG (chau), and at Kinshatsang in YÜNSEH (hien). Copper at Changfapu in CHINHIUNG (chau), at Siaunienfang in YÜNSEH (hien), and at Ninglau Mt. and Tsietsz'tang in TAKWAN (ting).
YUNGPEH (ting). Copper.

KINGDOM OF COREA.

Gold, silver, quicksilver, iron, coal, and sulphur.

MISCELLANEOUS MINERALS.

PROVINCE OF CHIHLI.

TAMING (Fu). Nitre on the Siau Ho.
SIUENHWA (Fu). Rock-crystal at Mt. Hwangtsie N. of city. Agates at Sz'kiautungtsing.

PROVINCE OF SHANSI.

TATUNG (Fu). Agates, sulphate of iron.
KIANG (chau). Sulphate of iron.
LUNGAN (Fu). Amber.
FANCHAU (Fu). Gypsum. Nitre. Rock-crystal in YUNGNING (chau).
TSEHCHAU (Fu). Rock-crystal. Realgar.

PROVINCE OF SHENSI.

SINGAN (Fu). Jade, in vicinity of copper and iron, at Tsungnan 50 li S. of city, at Mt. Lantien 30 li E. of LANTIEN (hien), and at Mt. Li, in vicinity of gold 2 li W. of LINGTUNG (hien).
SHANG (chau). Jade, in vicinity of gold, at Mt. Yanghwa N. E. of LOHNGAN (hien).
KIA (chau). Agate in FUKUH (hien) and SHINMUH (hien).
HANCHUNG (Fu). Amber in many localities. Feitsui (jadeite) in LIAYANG (hien). Realgar at Mt. Futu 60 li S. of FUNG (hien).
HINGNGAN (Fu). Jade at Mt. Ching 58 li W. of SINYANG (hien), and at Kantientsuhtung 60 W. of PEHHO (hien).
FU (chau). Iron pyrites and sulphur.

PROVINCE OF KANSUH.

KUNGCHANG (Fu). Agates. Realgar at Mt. Leangkung S. W. of MIN (chau). Nitre in NINGYUEN (hien), and HWUINING (hien).
KIAI (chau). Realgar. Sulphate of iron.
KINGYANG (Fu). Nitre in every Hien. Inkstone slate in NING (chau).

PROVINCE OF SHANTUNG.

TAINGAN (Fu). Amethyst.
YENCHAU (Fu). Amethyst.
ICHAU (Fu). Amethyst.
TUNGCHAU (Fu). Gypsum.

PROVINCE OF HONAN.

Nitre in all parts of the province.

PROVINCE OF HUPEH.

ICHANG (Fu). Agates. Nitre.

PROVINCE OF SZ'CHUEN.

CHUNG (chau). Amber in LIANGSHAN (hien).
KWEICHAU (Fu). Amber in WUSHAN (hien) and in TANING (hien).
SUITING (Fu). Amber in TATSOH (hien) or TA (hien).
MEI (chau). Nitre.

PROVINCE OF KIANGSI.

KWANGSIN (Fu). Rock-crystal in SHANGTSAU (hien).

PROVINCE OF HUNAN.

YUNGSHUN (Fu). Nitre in PAUTSING (hien).
YUENCHAU (Fu). Rock-crystal in YUNGSUI (ting).

PROVINCE OF KWEICHAU.

NGANSHUN (Fu). Amethyst.
HINGI (Fu). Realgar at Mt. Peinien.
TSUNI (Fu). Realgar 20 li E. of TUNGTSZ' (hien).
SZ'NAN (Fu). Jade in YINGKIANG (hien).

PROVINCE OF CHEHKIANG.

HANGCHAU (Fu). Gypsum at Mt. Shïkau in SUNGHO (hien).
KÜCHAU (Fu). Lapis-lazuli at Mt. Nien in CHANGSHAN (hien).
YENCHAU (Fu). Rock-crystal in SUINGAN (hien).
WANCHAU (Fu). Lapis-lazuli on Kinchingshï river, in LOTSING (hien).

PROVINCE OF FUHKIEN.

CHANGCHAU (Fu). Rock-crystal in CHANGPU (hien).
TAIWAN (Fu). Sulphur in CHANGHWA (hien).

PROVINCE OF KWANGTUNG.

KWANGCHAU (Fu). Amber. Amethyst at Mt. Pau in TUNGWEI (hien).
SHAUCHAU (Fu). Sulphate of iron.
KIUNGCHAU (Fu). Flint at Mt. Li. Whetstone at Mt. Shï. Large rock-crystals at Mt. Wutsz'.

PROVINCE OF KWANGSI

SZ'CHING (Fu). Realgar.
WUCHAU (Fu). Rock-crystal W. of TSANGHOH (hien).

PROVINCE OF YUNNAN.

YUNNAN (Fu). Nitre in YUNGMEN (hien).
WUTING (chau). Blue jade in Tungsan. Touchstone in the Kinshakiang river. Nitre, from wells, in YUENMAU (hien).
LIKIANG (Fu). Green and black jade in Mt. Mohpeh.
YUNGCHANG (Fu). Amber in TANGYUEH (chau). Agates at Mt. Manau in PAUSHAN (hien). Topaz and rock-crystal at Mungmitosz' in PAUSHAN (hien). Feitsui, and white and black jade at Maumotosz', and blue jade at TUNGYUEH (ting).

The mountains of Southern Yunnan seem to abound in precious stones.

The working of beautiful stones into objects of ornament, forms an important branch of industry in several of the large cities. Jade of various colors, serpentine, steatite,[1] and dendritic marbles, are made into an endless variety of household ornaments. Topaz, aqua-marine, pink turmaline, opaque sapphires, jadeite[2] (Feitsui), lapis-lazuli, sungurshï, a mineral similar to turquois, rock-crystal, garnets, and many other precious and semi-precious stones, are carved, with great labor and patience, in very intricate forms. Several snuff bottles carved out of blue corundum were seen, the cavity being very small at the neck, and enlarged symmetrically and polished in the interior.

No diamonds were seen in any of the lapidaries' shops, although the Chinese have a name for that stone. Emeralds are very rare, and although the Chinese name is lieupaushï (green precious stone), they are known among lapidaries as Sz'mulu, the name of Sumatra, whence they are probably obtained.

Rubies are more common, although often confounded with spinelles and hyacinths. Sapphires are frequent, and often of fine water and respectable size.

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[1] Much of the stone known as pagodite has been shown by Prof. G. J. Brush to be a compact pyrophyllite.

[2] Feitsui is, perhaps, the most prized of all stones among the Chinese. The *chalchihuitl*, a precious stone of the ancient Mexicans, as I have seen it in a mask preserved in the museum of Pract. Geol. in London, and in several ornaments in the collection of Mr. Squiers in New York, is, apparently, the same mineral. This fact is the more remarkable, as there is no known occurrence of this mineral in America.

APPENDIX.

APPENDIX No. 1.

Description of Fossil Plants from the Chinese Coal-Bearing Rocks.

By J. S. Newberry, M. D.

Cleveland, Ohio, September 25th, 1865.

Raphael Pumpelly, Esq.

Dear Sir: The fossil plants you were kind enough to submit to me for examination, though few in number and somewhat fragmentary, have proved to be of very special interest, since they supply the necessary data for determining, approximately, the age of the strata from which they were taken; and rather unexpectedly prove a large part of the great coal fields of China to be of Mesozoic age.

This conclusion is based on the entire absence of Carboniferous plants from the collection; and the presence of well-marked Cycads—species of *Podozamites* and *Pterozamites*, closely allied to, if not identical with, some heretofore found in Europe and America.

I give below, such descriptions of the several species contained in the collection, as could be framed from the somewhat meagre material submitted to me. Future observations, made upon a larger number of more perfect specimens, will be necessary before questions of specific identity or difference can be definitively settled—but it is scarcely probable that any facts, or specimens hereafter to be obtained, will require, modification of the view—that the coal basins which you visited are all Mesozoic and not Carboniferous.

We have, of course, no right to assume from the interesting facts your explorations have brought to light, that no Carboniferous coal exists in China, for it may very well happen, that as in our own country, coal seams of economical value, but of different ages, will be found there, at points not greatly removed from each other. But geologists will not fail to be deeply interested in the fact that so large portions of the coal basins of China, including beds of both anthracite and bituminous coal—worked for hundreds of years, probably the oldest coal mines in the world—are wholly excluded from the Carboniferous formation. So large is this coal-bearing area, indeed, that when joined to the Triassic, Cretaceous, and Tertiary coals of North America, they quite overshadow the Carboniferous coals of Europe and the Mississippi valley, and suggest the question, whether the name given to the formation which includes the most important European strata, has not been somewhat hastily chosen.

Another interesting feature in the fossil plants under consideration is the reappearance, at the far distant points from whence they come, of genera so well known in European and American geology—and the entire absence of the species of *Phylotheca, Glossopteris*, etc.—which have made the Indian and Australian coal floras so puzzling to the palæontologist. There are fragments of a new generic form—probably a Cycad—in the collection, and some obscure specimens that may represent other plants new to science, but the *Pecopteris, Sphenopteris, Podozamites, Pterozamites*, &c., have a very familiar look; and in their resemblance to well known forms, give fresh evidence of the monotony of the vegetation of the globe, previous to the introduction of the angiospermous forests of the Cretaceous epoch.

Whether the strata which have furnished these plants should be considered Triassic or Jurassic, remains to be determined by future observations, as the fossils as yet obtained can hardly be considered sufficient for the solution of that question.

From the "Kwei basin" we have numerous pinnæ of a species of *Podozamites*, undistinguishable from one found by Prof. Emmons in North Carolina, in strata now generally regarded as *Triassic:*

but associated with these are a few pinnæ of different form—much more elongated and acute—scarcely differing from those of a European Jurassic species (*P. lancolotus*, Lind.), still the evidence of identity is much stronger in regard to the former species than the latter.

From Pyünsz' we have a fine *Pecopteris*, with the falcate pinnules—so characteristic of the Mesozoic species, and indeed very accurately copying the form of *P. Whitbiensis*, a European Jurassic species—but unfortunately the strata which contain this fossil have been much metamorphosed, the coal converted to anthracite, and the nervation of the fern has been entirely obliterated, while the outline remains distinct.

Probably it will be found as difficult, or rather as impossible, in China, as it has been in this country, to identify all the subdivisions of the Mesozoic strata discernible in Europe; yet we shall doubtless gather there new proofs of the constancy of the order of sequence in geological history, and new evidence of the stability of the foundations on which geology, as a science, rests.

I have under my eye, as I write this letter, four collections of fossil plants which, though from very widely separated localities, are curiously linked together. They are:—

1st. Fossil plants, Cycads and Conifers, collected by myself from the gypsum formation (Triassic) at Abiquiu, New Mexico. Of this collection the most conspicuous and interesting plant is *Otozamites, Macombii*, N.

2d. A collection of fossil plants—Cycads and Ferns, received through Prof. Whitney from Sonora, Mexico, where they occur with coal strata and Triassic Mollusks. In this collection *Otozamites, Macombii* is associated with *Strangerites magnifolia*, Rogers, *Pecopteris falcatus*, Emm, and other plants occurring abundantly in North Carolina.

3d. A collection of fossil plants—Cycads, Conifers, and Ferns, from N. Carolina and Virginia, including beside the last two mentioned, and many others which are new, several species, apparently identical with European Triassic plants—of the genera *Haidingera*, *Gutbiera*, *Laccopteris*, &c., and among other Cycads, *Podozamites Emmonsii*, N.

4. The collection made by yourself in China—Cycads and Ferns—in which one of the most distinctly marked plants is *P. Emmonsii.*

In regard to the American localities cited above, there is, perhaps, no good reason for our withholding assent to the conclusion that the rocks furnishing the fossil plants are Triassic, but, when we remember how much difference of opinion there has been, and indeed still is, upon this subject, even in the light of large collections of fossils, we can hardly with propriety offer even a conjecture as to the *precise* age of the Chinese coal strata.

To recapitulate—one species of *Podozamites*, contained in the collection is apparently identical with an American Triassic species; the other more resembles a European Jurassic plant. The *Pterozamites* resembles both Triassic and Jurassic species, but is identical with neither.

The *Pecopteris* has certainly a remarkable likeness to *P. Whitbiensis*, which occurs both in the Liassic and Oolitic floras; and it is not yet certain that it is not also found in the Carolina and Richmond coal basins.

The *Sphenopteris* and *Hymenophyllites* are altogether new, and suggest no affinities of value in this connection, while the *Taxites*, *Equisetites*, &c., are too obscure to afford us any help.

Yours respectfully,

J. S. NEWBERRY

Pterozamites Sinensis, *Newb.*

Plate IX, Fig. 3.

Pt. fronde pinnata, parva, pinnis linearibus patentissimis integris, sub-approximatis vel remotis, sæpe curvatis, basi integris, apice rotundatis, nervis distinctis æqualibus simplicibus, rachi longitudinaliter striata.

This is a very neat and well-marked, though miniature species of *Pterozamites*, having the general aspect of *Pt. Oeynhausianus*, Goepp., but being less than half the size of that species, and the pinnæ are not at all decurrent on the rachis.

Perhaps of all known species *Pt. linearis*, of Emmons (Manual of Geol. fig. 194), from the Trias of North Carolina, most resembles this plant; but in that the pinnæ are much more crowded.

In the specimens obtained by Mr. Pumpelly, fragments of a number of different fronds are shown, all of about the same size, so we may conclude that the figure now given is a fair representation of the plant.

Locality.—In brown sandstone, with *Sphenopteris orientalis*, from Sanyü, west of Peking.

PODOZAMITES LANCEOLATUS, *Lindl.* sp.

PLATE IX, Fig. 7.

Zamia lanceolata, LIND. & HUTT. Foss. Flor. Vol. III, fig. 4.
Zamites lanceolatus, MORRIS, An. Nat. Hist. 1841.

I have provisionally, and with doubt, referred a few pinnæ of *Podozamites*, found in the collection, to this species. These pinnæ have almost precisely the form of those figured by Lindley, and are longer and narrower than those of *P. Emmonsii*—being linear-lanceolate, with an acute long drawn point, and an attenuated base.

In one character they differ from both the species to which I have referred; they seem to have been thicker and more coriaceous than either—the nerves being so deeply buried in the parenchyma as to be scarcely visible.

The distinctness of the nerves depends, however, on the surface of the leaflet exposed, and on the manner of fossilization—coarse micaceous shales, like that which contains the impression before us, rarely showing the nervation with distinctness.

The small number of the pinnæ, of the character I have described, in the collection, renders it difficult to determine, with accuracy, their specific relations. Their value, therefore, in a great degree, consists in the evidence they give us of the presence of the genus to which they belong in the rocks from which they were taken.

Locality.—Kwei basin on the Yangtse river, Province of Hupeh, China.

PODOZAMITES EMMONSII, *Newb.*

PLATE IX, Fig. 2.

P. fronde pinnata, pinnis distantibus integris alternis oppositisve, lanceolatis, apice attenuatis acutis, basi cuneatis, nervis crebris.

This is, apparently, the same plant as that described and figured by Prof. Emmons (Geol. N. Car. p. 331, pl. iii, fig. 7), under the name of *P. lanceolatus;* but that name having been appropriated for another species from the Oolite of Europe, it becomes necessary to give it another.

The specimens which are contained in the collection brought by Mr. Pumpelly, consist mostly of detached pinnæ, scattered in confusion over the surface of pieces of blue shale. These pinnæ agree perfectly in form and nervation with those of the Carolina plant. They are lanceolate in outline, and rather abruptly narrowed to an acute termination at either end. The nerves are fine and numerous, but distinctly visible, converging to a common point at the remote extremity. The rachis to which all were, and a few are still attached, was slender, and striated longitudinally. The specimen figured by Prof. Emmons is the basal portion of the frond where the rachis is strongest. Higher up this character, to which he attaches some importance, would be lost. The Carolina plant is abundant in the upper plant beds, where it is associated with several species supposed to be identical with some from the Trias (Keuper) of Europe, such as *Pecopteris Stutgardtensis*, *Laccopteris germinans*, &c.; it is, however, not quite certain that there are not also found there some species which are found in the Jurassic of Europe. More careful study of this flora will be necessary before that question can be settled; but the beds which contain *P. Emmonsii* are now generally supposed to represent the Keuper of Europe, and the evidence which this gives, as to the age of the Chinese rocks containing it, so far as it goes, points to the same date for them.

Locality.—Kwei basin on the Yangtse river, Province of Hupeh, China.

16 July, 1866.

Sphenopteris orientalis, *Newb.*

Plate IX, Figs. 1 and 1 *a*.

S. fronde tripinnata, rachide longitudinater sulcata, pinnis lanceolatis vel linearibus, acutis, pinnulis sessilibus summis lobatis, inferioribus laciniatis, laciniis rotundatis, apice sæpe emarginatis nervis tenuis, in lobis dichotomis.

This species is more largely represented in the collection than any other, and yet all the specimens consist of comparatively small fragments of a frond of considerable size.

In nearly all of these specimens a remarkable inequality is observable between the pinnules of the upper and under side of the rachis of each pinna—the upper ones being shorter, broader, and more upright; the lower ones elongated, narrow, and more oblique to the rachis.

Probably this is a constant character in the plant, as examples of similar diversity of form are not wanting among living ferns; but I have seen instances of distortion not unlike this in ferns imbedded in rocks which had been much disturbed.

In general aspect this species is not dissimilar to some Carboniferous ferns, such as *Sph. Schlotheimi*, *Sph. tridactylites*, &c., but it still more resembles the Oolitic species *Sph. denticulata* and *Sph. hymenophylloides*, and the Triassic species *Sph. dichotoma*, Alth. It is also considerably like a Triassic species not yet described, found near Baltimore, Md. From all these, however, it is apparently distinguished by the dissimilarity of form in the pinnules of the upper and lower side of the pinnæ, and by the shape of the lobes of the pinnules. In the upper pinnules the lobes are spatulate; in the lower, fan-shaped. Some of the lobes are straightly emarginate at the summit, but generally they have the appearance of being rounded and entire.

Locality.—Sanyü Chaitang basin, west of Peking, China.

Pecopteris Whitbiensis? *Brong.*

Plate IX, Fig. 6.

From "Piyünsz', west of Peking," in a coarse shale charged with the bitumen driven off from the associated coal seam—now anthracite—is a fragment including several pinnæ of the frond of a large fern, which bears a marked resemblance to *P. Whitbiensis;* so much so, that if the nervation, which is obliterated in the specimen before us, were found to be similar, I should have no hesitation in referring it to that species, as no Carboniferous ferns exhibit that peculiar falcate outline of the pinnules, so marked in *P. Whitbiensis*, *P. dentata*, Lind. (*P. denticulata*, Brong.), etc.

P. Whitbiensis is in Europe found both in the Lias and Oolite, according to Brongniart, but is regarded as distinctly a Jurassic species. It has been supposed to occur in the Richmond coal basin in this country; but *some* of the specimens thought to represent the plant, have been found by Prof. Heer to have a reticulated nervation, and therefore to be, both specifically and generically, distinct from *P. Whitbiensis.* A careful examination of all the specimens collected in this country, supposed to belong to *P. Whitbiensis*, will be necessary before we can decide whether it has indeed been found in the so-called Triassic strata of America; and unfortunately we must wait till other specimens, and such as are in a better state of preservation, shall be brought from China before we can positively affirm that it occurs in the coal strata of that country.

Locality.—Shale over anthracite coal, at Piyünsz', west of Peking, China.

Hymenophyllites tenellus, *Newb.*

Plate IX, Fig. 5.

H. fronde bipinnata, parva, delicatula; pinnis lineari-lanceolatis, pinnulis laciniatis; laciniis filiformis vel spatulatis acutis; sori subrotundi laciniarum apicibus insidentes.

In the plumbaginous schist brought from "Piyünsz', west of Peking," are numerous fragments of a frond of a species of *Hymenophyllites*, which seems to be undescribed. These fragments are so small that no clear idea can be gained from them of the magnitude or form of the frond; but it was

doubtless a delicate fern of small size, the pinnules deeply cut into linear or spatulate lobes, those of the fertile portions of the frond being specially slender, and bearing the sori at the extremity of each lobe. A fruit-bearing fragment visible in one of the specimens before us calls to mind Lindley's *Tymfanophora racemosa*, which is now regarded as the fertile portion of the frond of *Coniopteris Murrayana.*

This fossil also occurs at Sanyü, near Chaitang, with *Sphen. orientalis*, thus linking together, geologically, these two localities.

TAXITES SPATULATUS, *Newb.*

PLATE IX, Fig. 4.

T. foliis coriaceis lineari-lanceolatis vel spatulatis, curvatis, apice rotundatis, basi cuneatis, nervo medio valde distincto.

In a yellow sandy schist, from near the Futau mine at Chaitang, with pinnæ of *Podozamites*, are numerous linear or spatulate one-nerved leaves, evidently derived from some coniferous tree, apparently of the family of Taxineæ, though larger than the leaves of any of the known Yews.

By their size, curved outline, cuneate base, and their variable width, these leaves bear some resemblance to some of those which have been referred to the genus *Podocarpus*, but with one exception all the described fossil species have been found in Tertiary rocks. The exception referred to is *Podocarpites acicularis*, Andræ, from the Lias of Steierdorf, in which the leaves are very long and narrow, having more the form of those of a pine.

Podocarpus Taxites, Unger (Flor. Foss. v. Sotzka), has almost precisely the form of some of the leaves before us; but it is very doubtful whether that was really a *Podocarpus.*

Brongniart has enumerated in his Prodromus a *Taxites podocarpoides*, from the Oolite of Stonesfield, but no figure or description of it has yet been given. Possibly that species may have relations with the one under consideration, which would give the latter a value in determining the precise age of the rocks which contain it.

APPENDIX NO. 2.

Analyses of Chinese and Japanese Coals.

Made for R. Pumpelly by Mr. JAMES A. MACDONALD, M. A., of the Sheffield Laboratory, Yale College.

IN the following analyses each determination is the mean of two closely agreeing ones. For the water determination the coal was pulverized and heated in an air-bath at 110° C. until it gave a constant weight. A portion was then ignited in fragments, in a closed crucible, to determine the "volatile matter." The ash was estimated in the usual manner by incineration.

I. TATSAU mine (43 feet seam) near Chaitang.

Hard anthracite. Decrepitates very slightly, and yields a little HO in a closed tube. Spec. grav. 1.57.

Carbon	89.81
Volatile matter	3.08
Water	2.67
Ash	4.44
	100.00

II. FUTAU mine. Chaitang (west of Peking).

Bright, bituminous, coking coal, yielding a little HO in the closed tube. Spec. grav. 1.30.

Carbon	85.77
Volatile matter	11.94
Water	0.35
Ash	1.94
	100.00

III. CHINGSHUI (near Chaitang W. of Peking).

Soft, bituminous coal, coking in a tube and giving some HO. Spec. grav. 1.37.

Carbon	81.32
Volatile matter	5.62
Water	0.36
Ash	12.70
	100.00

IV. TEYIH mine (near Muntakau W. of Peking).

Soft, crumbling anthracite. Gives some HO in a closed tube. Spec. grav. 1.74.

Carbon	80.75
Volatile matter	5.43
Water	2.42
Ash	11.40
	100.00

V. TASHITUNG mine (Fangshan S. W. of Peking).

Hard anthracite, coated with some carbonate. Decrepitates and gives off some HO in a closed tube. Spec. grav. 1.84.

Carbon	86.62
Volatile matter	4.64
Water	2.64
Ash	6.10
	100.00

VI. KWEI (first mine above Kwei on the upper Yangtse in Hupeh).

Rather a soft coal. When heated in a closed tube gives off HO, and a slightly bituminous odor, without decrepitating. Spec. grav. 1.44.

Carbon	85.63
Volatile matter	4.10
Water	0.38
Ash	9.89
	100.00

VII. Mine of SIANGTUNG (in Hunan).

Hard, fine-grained anthracite. Gives off HO, and decrepitates violently in a closed tube. Spec. grav. 1.65.

Carbon	96.21
Volatile matter	0.65
Water	1.45
Ash	1.69
	100.00

VIII. Another coal from SIANGTUNG.

Hard anthracite. Gives HO in a closed tube, and decrepitates but slightly. Spec. grav. 1.61.

Carbon	94.59
Volatile matter	1.18
Water	1.65
Ash	2.58
	100.00

IX. LAICHA HO (Southern Hunan).

Hard anthracite. Yields HO and considerable sulphur on heating in a closed tube. Spec. grav. 1.47.

Carbon	88.27
Volatile matter	2.92
Water	0.80
Ash	8.01
	100.00

X. Hangchau (Southern Hunan).
Rather soft, bituminous coal, coking in a closed tube. Spec. grav. 1.68.

Carbon	71.80
Volatile matter	15.89
Water	0.65
Ash	11.66
	100.00

XI. Mine near Fangshan (S. W. of Peking).
Hard anthracite. Yields HO, and decrepitates in a closed tube. Spec. grav. 1.83.

Carbon	90 02
Volatile matter	2.68
Water	2.20
Ash	5.10
	100.00

XII. Coal from Tatung in Shansi.
Clear black, moderately hard bituminous coking coal. Decrepitates slightly. Spec. grav. 1.30.

Carbon	65.30
Volatile matter	28.69
Water	1.47
Ash	4.54
	100.00

XIII. Coal from Douy (island of Sagalien).
Clear black, bituminous coking coal. Spec. grav. 1.31.

Carbon	67.51
Volatile matter	22.98
Water	3.51
Ash	6.00
	100.00

XIV. Coal from Iwanai (island of Yesso).
Clear, smooth, black or brownish coal. Gives off HO, and cokes in a closed tube. Spec. grav. 1.26.

Carbon	60.26
Volatile matter	29.72
Water	2.30
Ash	7.72
	100.00

XV. Yingwo mine (Fangshan S. W. of Peking).
Soft crumbling anthracite. Yields considerable HO in a closed tube. Spec. grav. ?

Carbon	77.58
Volatile matter	3.63
Water	2.50
Ash	16.29
	100.00

APPENDIX No. 3.

Letter from Mr. Arthur Mead Edwards on the Results of an Examination, under the Microscope, of some Japanese Infusorial Earths and other Deposits of China and Mongolia.

New York, January 14, 1866.

Raphael Pumpelly, Esq.

Dear Sir: I have, agreeably to your request, made a microscopical examination of the specimens of earths you submitted to me some time since, and have to report thereon as follows:—

They were thirteen in number, and the results of examining each one separately and carefully is recorded below. With regard to the two specimens numbered 6 and 9, in which I have found the siliceous loricæ of Diatomaceæ, I have to regret that the time at my disposal lately has been so short that I have been unable to identify the various species detected therein, much less have I been able to do as I would have wished, that is to say, transmit to you at this time a complete list with descriptions and figures of the supposed new forms.

No. 1. "*Efflorescence from the plains of the Kirnoor, Mongolia.*"

This specimen contains some straight sponge spiculæ and broken crystalline particles of a deep olive-green color; otherwise it consists mostly of fine particles of sand. From the presence of the sponge-spiculæ I judge this deposit to be decidedly of aquatic origin and probably marine; although the form of the spiculæ, as well as I can tell from their generally broken condition, is such that they may have belonged to a fresh-water species of sponge.

No. 2. "*Terrace deposit (loam of lower terrace) Tê Hai, Mongolia.*"

Under the microscope this is very similar to the above, that is to say, it contains many of the green crystalline particles found in No. 1, but no sponge-spiculæ that I have been able to detect.

No. 3. *Efflorescence (with sand), from the flat at the Tê Hai Mongolia.*"

This is also very like the first in appearance, in containing green crystals, but, like the second specimen it contains no sponge-spiculæ, so that in neither of these two last numbers have I found anything that would assist in determining their origin.

No. 4. "*Gobi limestone (steppe deposit in part), Nov. 28, 1864.*"

Consists almost entirely of fine white particles of calcareous matter, but shows nothing to indicate the circumstances or conditions under which it was deposited. This was to be expected as the microscope rarely reveals anything peculiar in limestones, their origin being best denoted by the character of the large fossils when these are present.

No. 5. "*Lake loam, Siwan, N. Chihli,*" is mostly sand, and contains a few of the before mentioned green crystals, but no traces of the remains of organized beings.

No. 6. "*Forming bluff near Nietanai, Yesso.*"

No. 9. "*From bluff near Nietanai, Yesso.*"

These both evidently belong to the same deposit, taken at different depths most likely, as is evident from the remains of organized forms which they contain. They are plainly from a marine tertiary stratum similar in character to that discovered by Prof. Rogers underlying the cities of Richmond and Petersburg in Virginia, and also like that found by Prof. W. P. Blake at Monterey in California. The last mentioned deposit I have at present under examination for the State survey of California, and it has been found by Prof. Whitney, and his coadjutors of the survey, at different points extending some hundreds of miles down the Pacific coast, varying slightly in appearance, color, hardness, or the grouping of the forms contained in it, as it was collected at various localities, but plainly showing

that there is one extended deposit covering a great extent of country. In fact the Japan specimens resemble those from California in a very marked degree, and much more so than the Virginian ones, containing almost identically the same species of Diatomaceæ that I have found therein. I am not, at present, prepared to give a list of those species, but the following genera have been identified, all of which, with the exception of the last, are exclusively marine, but the species of that last genus *Cocconeis*, found in this deposit, are decidedly of marine origin also.

Arachnoidiscus.	*Creswellia.*
Auliscus.	*Dictyocha.*
Asterolampra.	*Isthmia.*
Actinoptychus.	*Gephyria.*
Aulacodiscus.	*Grammatophora.*
Stictodiscus.	*Rhabdonema.*
Coscinodiscus.	*Biddulphia.*
Triceratium.	*Cocconeis.*

Doubtless species belonging to other genera will be detected hereafter, when I study these specimens more attentively, when it is my intention to make out a full list of the species I may find and publish it, with descriptions and figures of such as I consider new or undescribed, through the medium of some one of our scientific societies. Meantime I send you herewith a couple of slides of this material, mounted in such a manner that you can judge for yourself of its richness in microscopic forms and their beauty, and in many cases, identity with those found in the Californian stratum, a slide of which accompanies them.

No. 7. "*Terrace deposit (loam) from the valley north of the mountains of Sinpaungan.*"
Contains little but sand with a very few of the green colored crystals above mentioned interspersed through it.

No. 8. "*Terrace deposit (loam) from Siwan, N. Chihli, China.*"
This contains nothing of interest or by means of which its origin can be traced.

No. 10. "*Gobi Sandstone, steppe deposit, Dec.* 2, 1864."
Consists entirely of clean coarse sandy particles, semi-crystalline in character, and with, or in which the microscope reveals, no traces of organic remains.

No. 11. "*From the beds of volcanic ashes at Isoya, west coast of Yesso, Japan.*"
This specimen was examined in a superficial manner at first, but, besides consisting for the most part of pinkish particles of minute size whose origin could hardly be guessed at, was deemed of very little interest. A closer and more thorough examination, however, with higher power glasses revealed decided traces of organic remains and those of an entirely unlooked for character, that is to say, there were found in it, although only in extremely small numbers, straight sponge spiculæ as well as globular, so-called, "gemmules" from sponges, and at the same time dotted ducts from the woody portion of some exogenous plant. Besides these, strange to say, I found fragments of the siliceous epidermis of three or perhaps four species of Diatomaceæ, decidedly aquatic plants and, in this case, all marine in their habit. The genera represented in these very rare and minute fragments were *Arachnoidiscus, Cyclotella, Isthmia,* and probably *Coscinodiscus.* Besides these the green colored crystals mentioned above, as having been detected in several of the earths examined, were seen in this specimen showing that there exists some connection between these various specimens in their origin.

No. 12. "*Alkaline sand from the shore of Lake Kirnoor, Mongolia.*"
No. 13. "*Sand deposited in the valleys around Lake Bilikanoor, Gobi desert.*"
In neither of these specimens could I find the slightest traces of the remains of organized beings or anything else by means of which I could judge of their origin. Thus, although the results of my examination, conducted in the most careful manner, are in most cases but negative, yet, even therefore they are of interest, and you will be better able to judge than I am of their value. The dis-

covery of another marine stratum consisting of the siliceous epidermis of Diatomaceæ in such an unlooked for locality, is of the greatest interest, and will, it is to be hoped, assist somewhat in deciding the true position of such commonly called "infusorial earths." Its similarity to that found on the Pacific coast of North America, would seem to point to its identity in time with that widely extended stratum, and doubtless the results which we have a right to expect from the very complete survey of the State of California, now being carried on, will shed much light on this point. Prof. Toumey placed the stratum of Virginia much lower than had been done by Prof. Rogers, and the correctness or incorrectness of his views in this respect and as bearing on the Californian and Japan deposits, can only be demonstrated after a careful examination and comparison of the adjacent strata. It is desirable that the layer extending from Petersburg in Virginia almost to Baltimore in Maryland, should be examined by a competent observer, and its characters be carefully determined and noted so that they can be compared with those of the Pacific. I hope, ere long, to be able to contribute something towards that end, but extended suites of specimens will have to be collected before we can hope to arrive at any very definite results. Meantime the discovery of such a stratum in Japan will lead to searches for similar deposits in other parts of the world, and I trust and fully expect with success.

Respectfully yours,

ARTHUR MEAD EDWARDS.

INDEX.

F = *Fu*, departmental city; C = *Chau*, sometimes departmental-, but generally district-city; H = *Hien*, district town; T = *Ting*, and Ts = *Tsang*, smaller towns.

17 August, 1866.

PUBLISHED BY THE SMITHSONIAN INSTITUTION,

WASHINGTON CITY,

AUGUST, 1866.

PLATE 1.

SEE CHAPTER II.

Section along the Yangtse Kiang from the Pacific Coast to Pingshan (hien) in Western Sz'chuen.

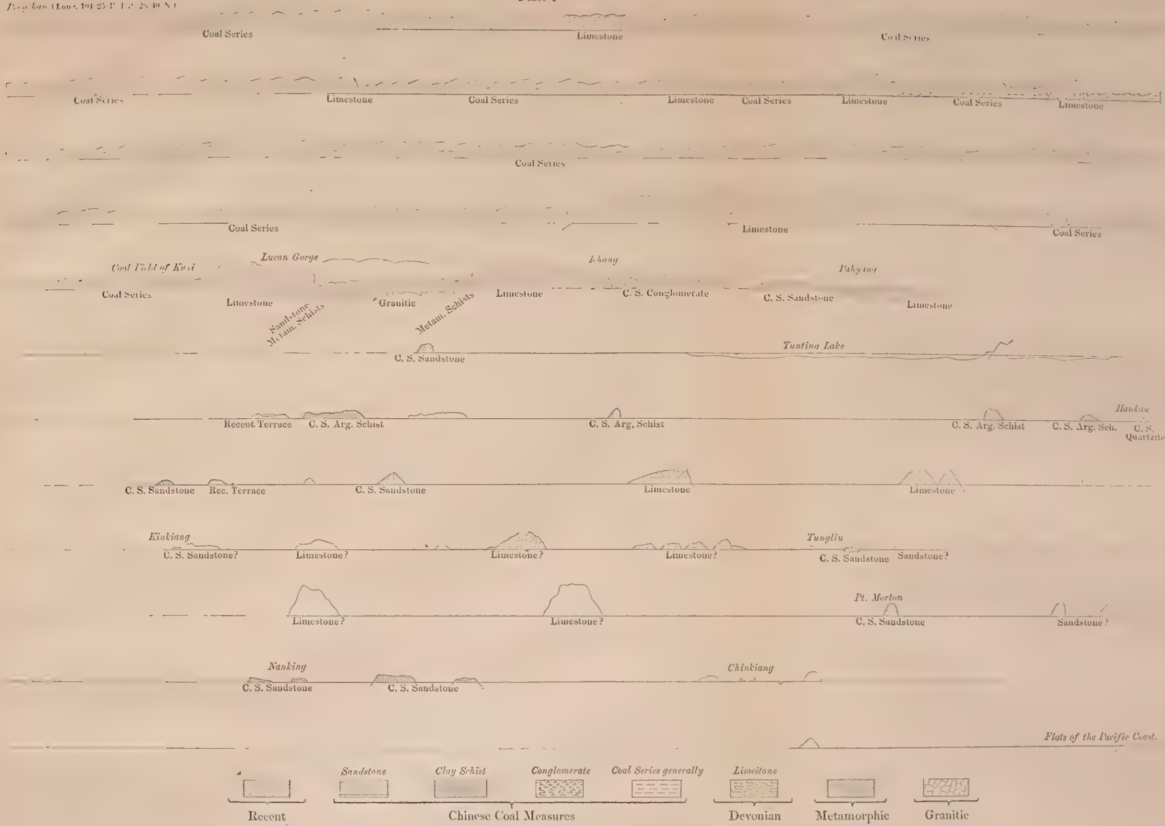
The portion of the section lying between the coast and the coal-field of Kwei is based on the observations of the author; the remainder is deduced from the observations of Capt. Blackiston, and from the study of the mineral productions of the province of Sz'chuen.

The horizontal distances are taken from the Admiralty charts of the river between the coast and the Tungting lake; thence to Pingshan (hien), from Blackiston's chart of the Upper Yangtse.

The vertical distances east of the Tungting lake are from the Admiralty surveys; west of the Tungting lake they are merely estimated.

Pingshan (Long. 104°2

Plate 1



Pacific Coast to Pingshan in Sz'chuen.

Horiz. Scale 6.28 miles to 1 dec. inch. *Heights* 4500 feet to 1 dec. inch.

PLATE 2.

See Chapter IV.

Route Map of the Yang Ho District.

This map is intended to show roughly the geological and topographical features of a portion of the boundary between the Great Plateau of Central Asia and the mountains of China.

The survey was made by the author from observations with a dioptric compass, the distances being measured by timing a horse whose gait was well known. The work was plotted in the field on a Mercator basis. The route followed in the mountains, immediately west of Peking, is not indicated; on the rest of the map, from Changkiakau (Kalgan) westward, it is marked by the, generally zigzag, line running through most of the villages. Going westward from Changkiakau (Kalgan) by the northern, and returning by the southern route, the plotting overlapped at Changkiakau by five and a half miles, an excess which represents the final, uncompensated, error of the work.

The positions of Siuenhwa, Tatung, and Tungching, are from the Jesuit astronomical observations; that of Peking is from those of the Russian astronomers.

The section lines of Plate 3 are represented on this map.

Plate 2

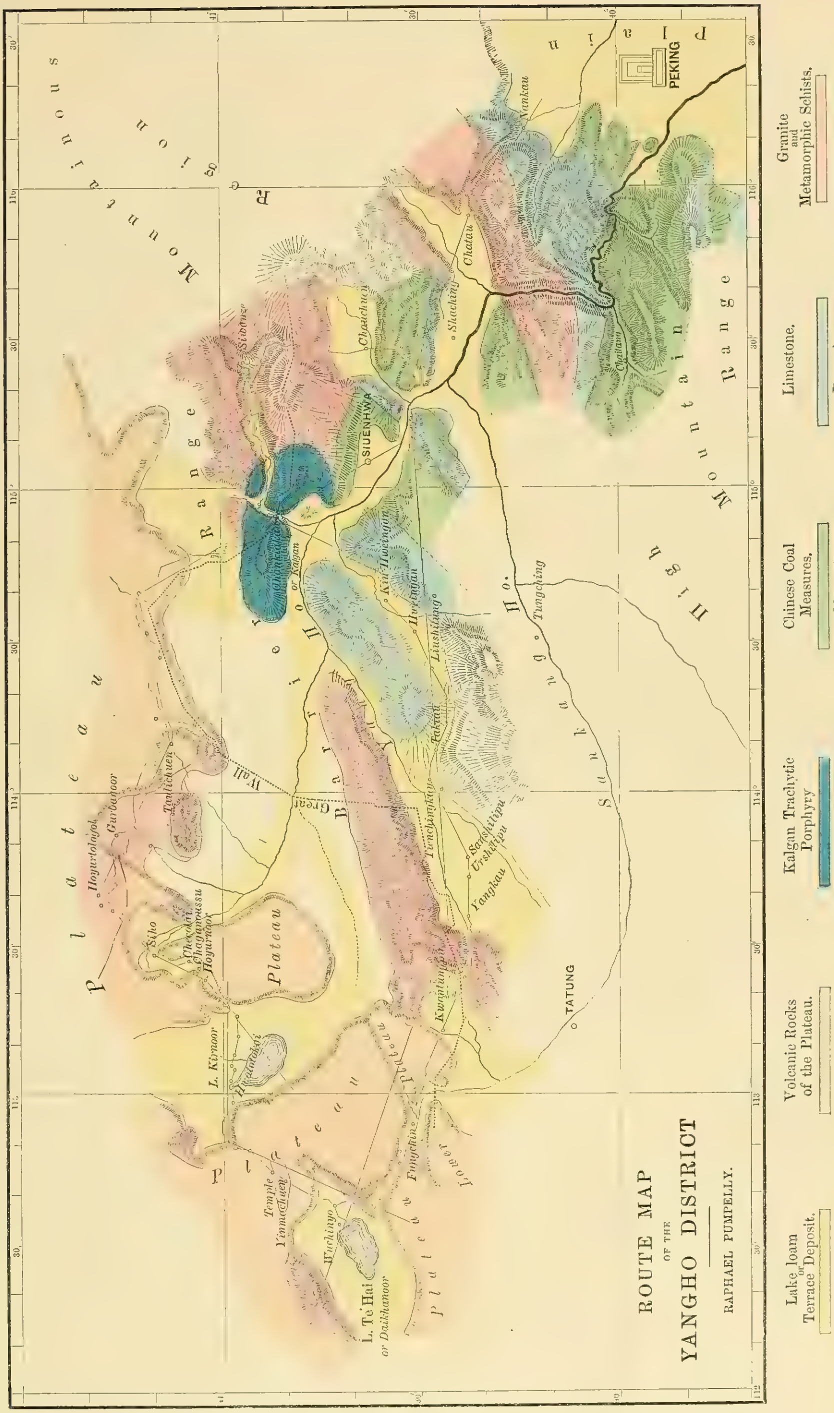

ROUTE MAP
OF THE
YANGHO DISTRICT
RAPHAEL PUMPELLY.
Lake loam or Terrace Deposit.
Volcanic Rocks of the Plateau.
Kalgan Trachytic Porphyry
Chinese Coal Measures, Mesozoic.
Limestone, Devonian.
Granite and Metamorphic Schists.
PEKING
Nankau
Chatau
Shaching
Chaichuen
SIUENHWA
Kalgan
Hwaingan
Liushituing
Tungching
TATUNG
Great Wall
Mountain Region
Plateau
Range
High Mountain Range
Yang Ho
Sang kang Ho
L. Kirnoor
L. Te Hai or Daikhanoor
Plain

PLATE 3.

SEE CHAPTER IV.

Geological Sections in Northern Chihli and Southern Mongolia.

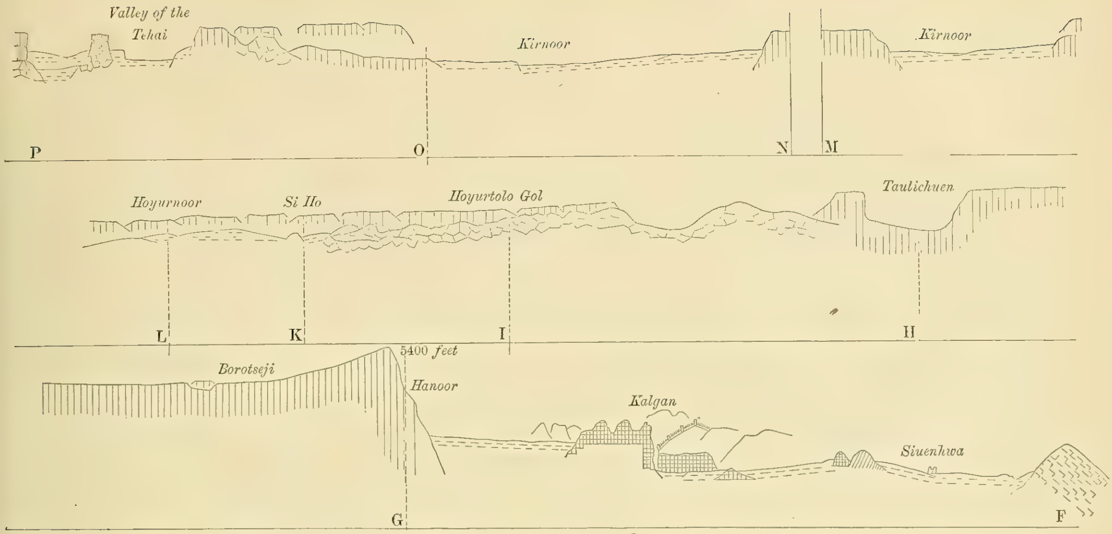
Siuenhwa to Daikha Noor.

Nankau to Daikha Noor.

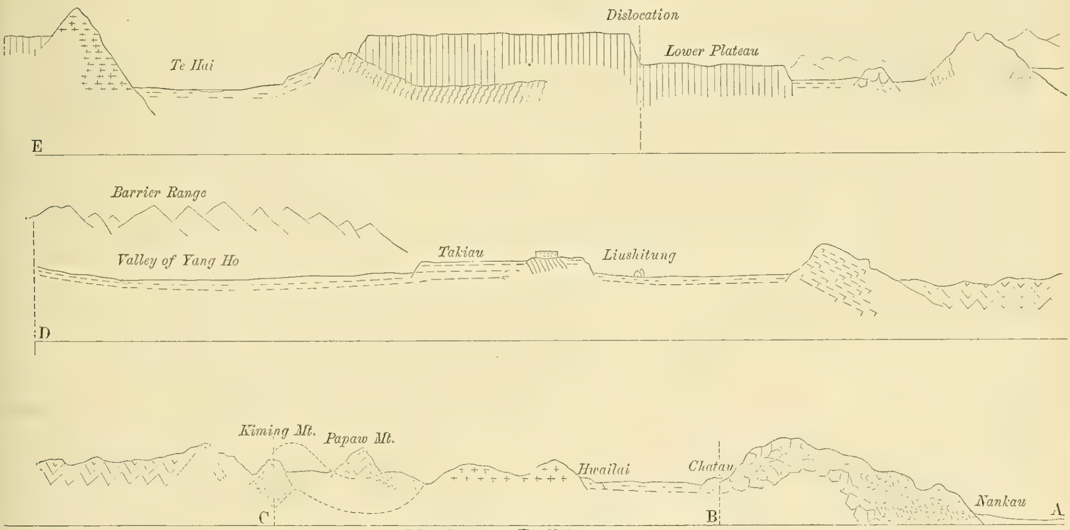
The heights are merely estimated, excepting that of the edge of the plateau, near Hanoor, which is from the measurements of Messrs. Fuss and v. Bunge.

Unfortunately the capital letters indicating breaks in the course of the section lines were omitted on the map, Plate 2.

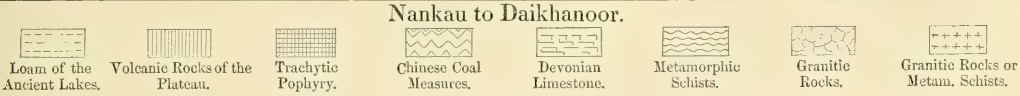
Plate 3



Siuenhwa to Daikha Noor.



Nankau to Daikhanoor.



Horiz. Scale 10.46 miles to 1 dec. inch. *Heights* 5000 feet to 1 dec. inch.

PLATE 4.

SEE CHAPTER V.

Maps Representing the Historical Changes in the Course of the Yellow River, or Hwang Ho.

Map I. Lower course of the Yellow river from the time of Yu down to B. C. 602. Also the ancient mouths of the Yangtse Kiang.

Map II. Course after the first great change during the Chow dynasty (B. C. 602).

Map III. Course during the third century, B. C.

Map IV. Course resulting from changes about 132 B. C.

Map V. Second great change about 11 B. C.

Map VI. The channels as they existed during the Tang and five succeeding dynasties, from A. D. 70 to A. D. 1048.

Plate 4

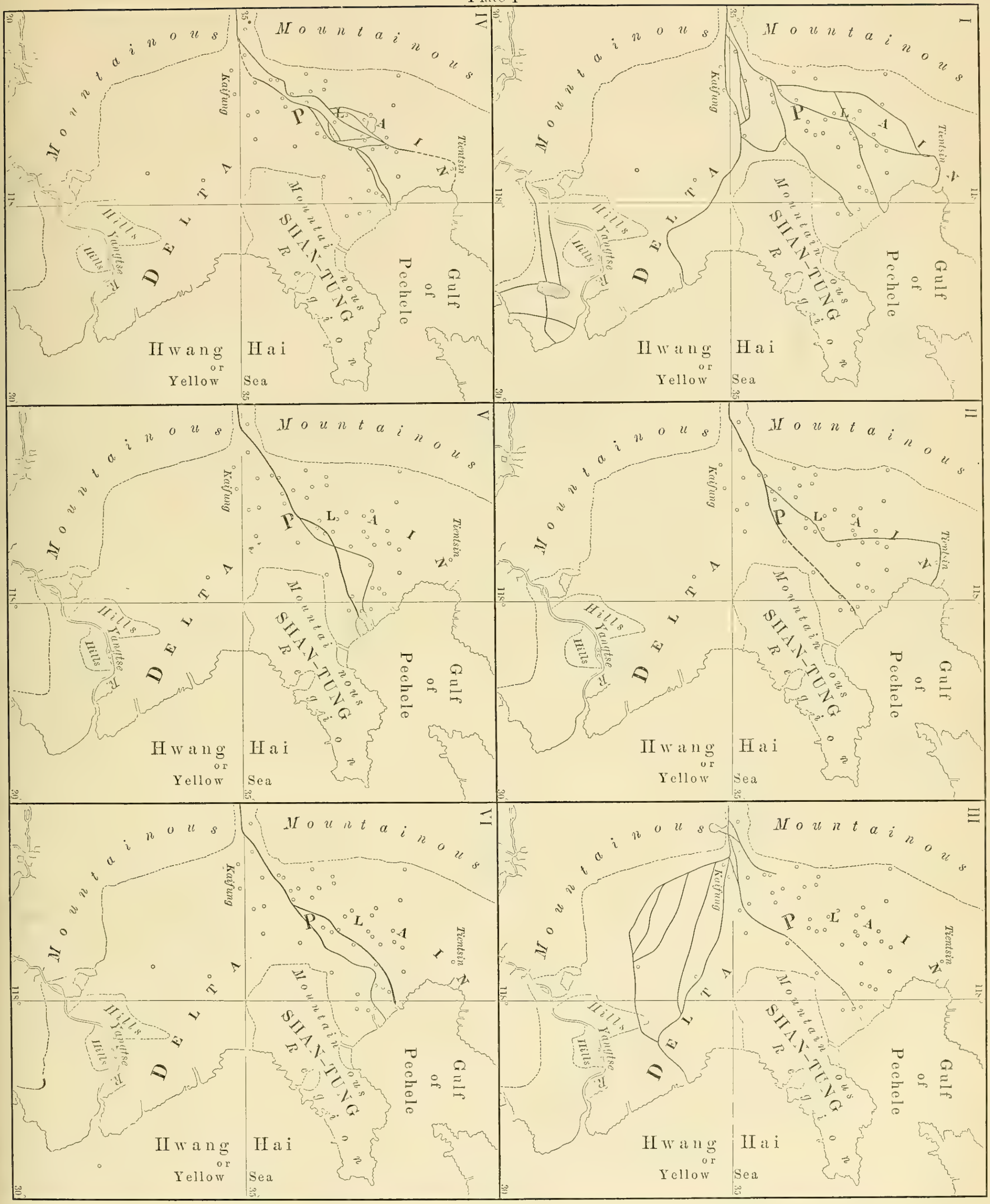

I
II
III
IV
V
VI
Mountainous
Mountainous
Kaifung
PLAIN
Tientsin
DELTA
Hills
Hills
Yangtse R.
SHAN-TUNG
Mountainous
Region
Gulf of Pechele
Hwang Hai or Yellow Sea
118°
35°
30°

PLATE 5.

SEE CHAPTER V.

Maps Representing Historical Changes in the Course of the Yellow River, or Hwang Ho.—Continued.

Map VII. The course under the Sung dynasty, A. D. 1048 to A. D. 1194.

Map VIII. The course under the Kin dynasty.

Map IX. The course under the Yuen (Mongol), and, so far as the channel running due east from Kaifung is concerned, under the Ming and Tatsing (Manchu) dynasties down to the middle of the present century. That portion of the Imperial canal lying north of the Yellow river is indicated, it being mainly in the channel excavated by the river during the Kin dynasty.

Map X. Represents the last change, which occurred within the last ten or fifteen years.

Map XI. Comprehensive map of the Yellow river, including the delta-plain and the ancient lake system, and the supposed former channel of the river through the lakes to the Gulf of Pechele.

Plate 5

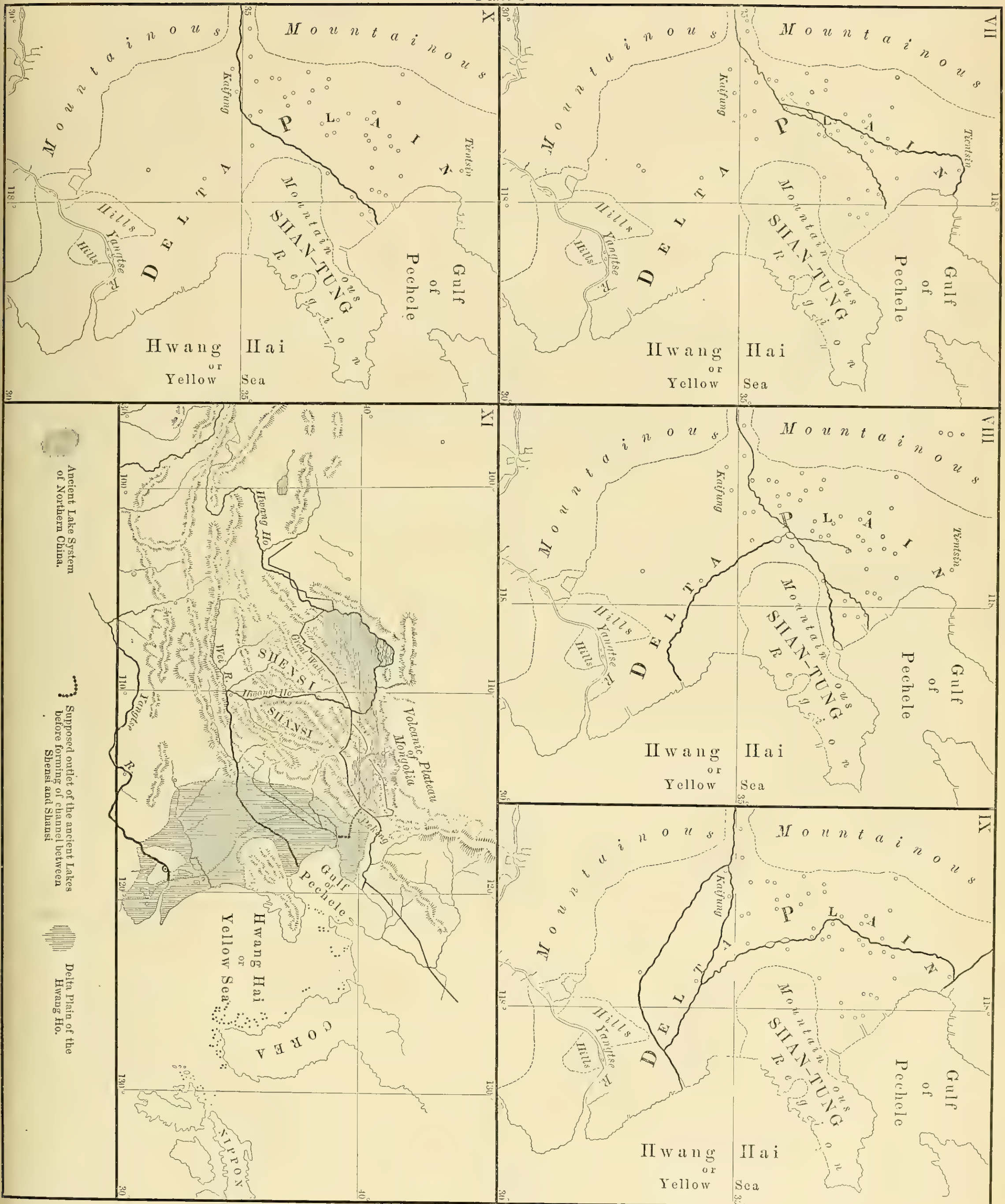

VII
VIII
IX
X
XI
Mountainous
PLAIN
DELTA
Hills
Yangtse R.
Kaifung
Tientsin
SHAN-TUNG
Mountainous Region
Gulf of Pechele
Hwang Hai or Yellow Sea
Hwang Ho
Wei R.
SHENSI
SHANSI
Great Wall
Volcanic Plateau of Mongolia
Peking
COREA
NIPPON
Ancient Lake System of Northern China.
Supposed outlet of the ancient Lakes before forming of channel between Shensi and Shansi
Delta Plain of the Hwang Ho.

PLATE 6.

SEE CHAPTER VI.

Hypothetical Map of the Geological Structure of China, based on Observations in the North and in the Basin of the Yangtse Kiang, and on a Study of the Mineral Productions of the Empire.

The geographical basis of this map is taken from Arrowsmith's map, published in Blackiston's "Five Months on the Upper Yangtse."

I have altered the position of the Lower Yellow river on the map, to make it agree with its present course.

Plate 6

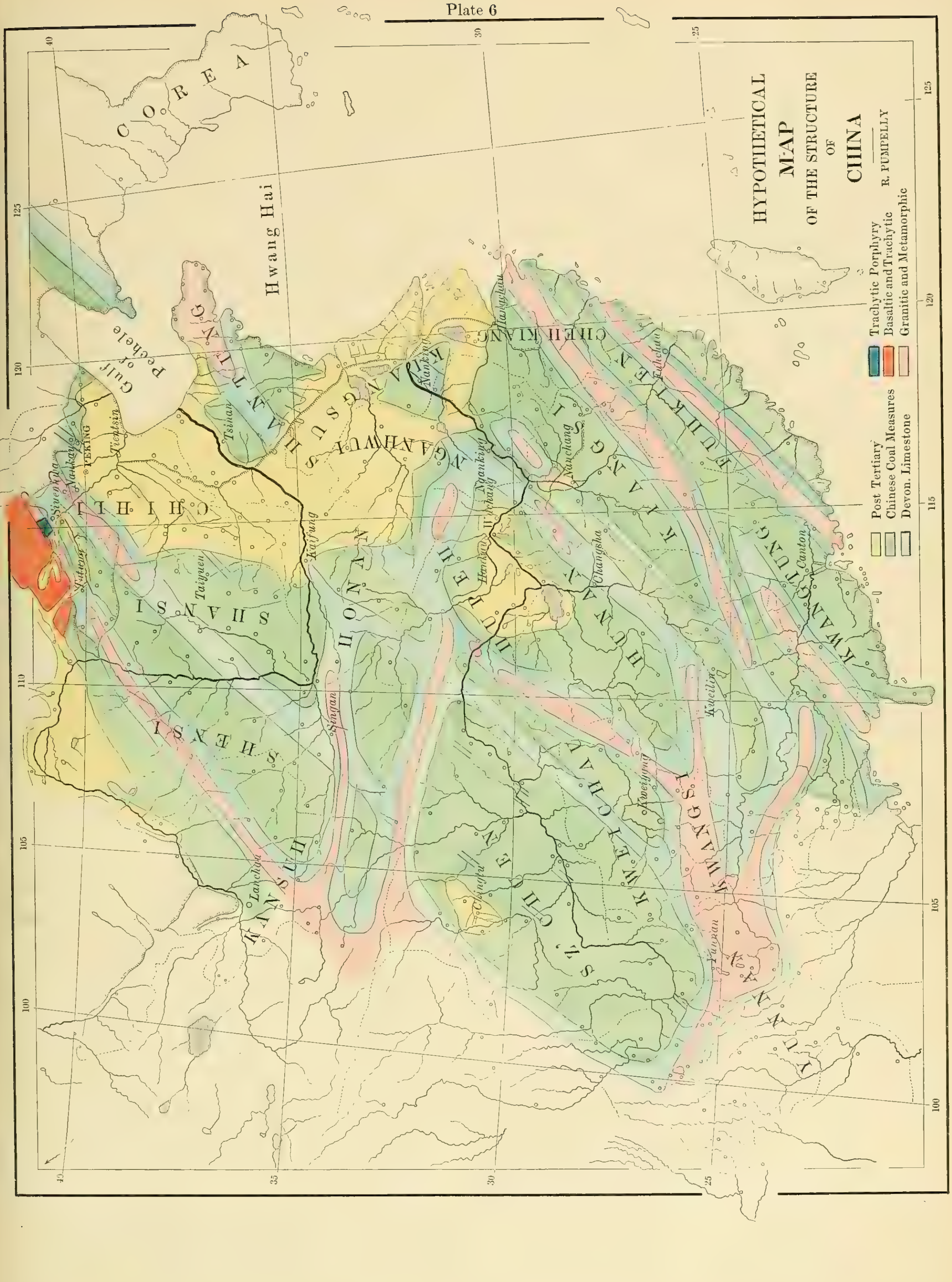

HYPOTHETICAL
MAP
OF THE STRUCTURE
OF
CHINA
R. PUMPELLY
Post Tertiary
Chinese Coal Measures
Devon. Limestone
Trachytic Porphyry
Basaltic and Trachytic
Granitic and Metamorphic
COREA
Hwang Hai
Gulf of Pechele
CHIHLI
SHANTUNG
KIANGSU
NGANHWUI
CHEH KIANG
KIANGSI
FUHKIEN
KWANGTUNG
HUNAN
HUPEH
HONAN
SHANSI
SHENSI
KANSUH
SZ'CHUEN
KWEICHAU
KWANGSI
YUNNAN
PEKING
Tientsin
Taiyuen
Kaifung
Singan
Tsinan
Nanking
Hangchau
Nganking
Hankau
Wuchang
Nanchang
Changsha
Fuhchau
Canton
Kweilin
Kweiyang
Yunnan
Chingtu
Lanchau

PLATE 7.

See Chapter VII.

Map of the Sinian (N. E., S. W.) System of Elevation in Eastern Asia.

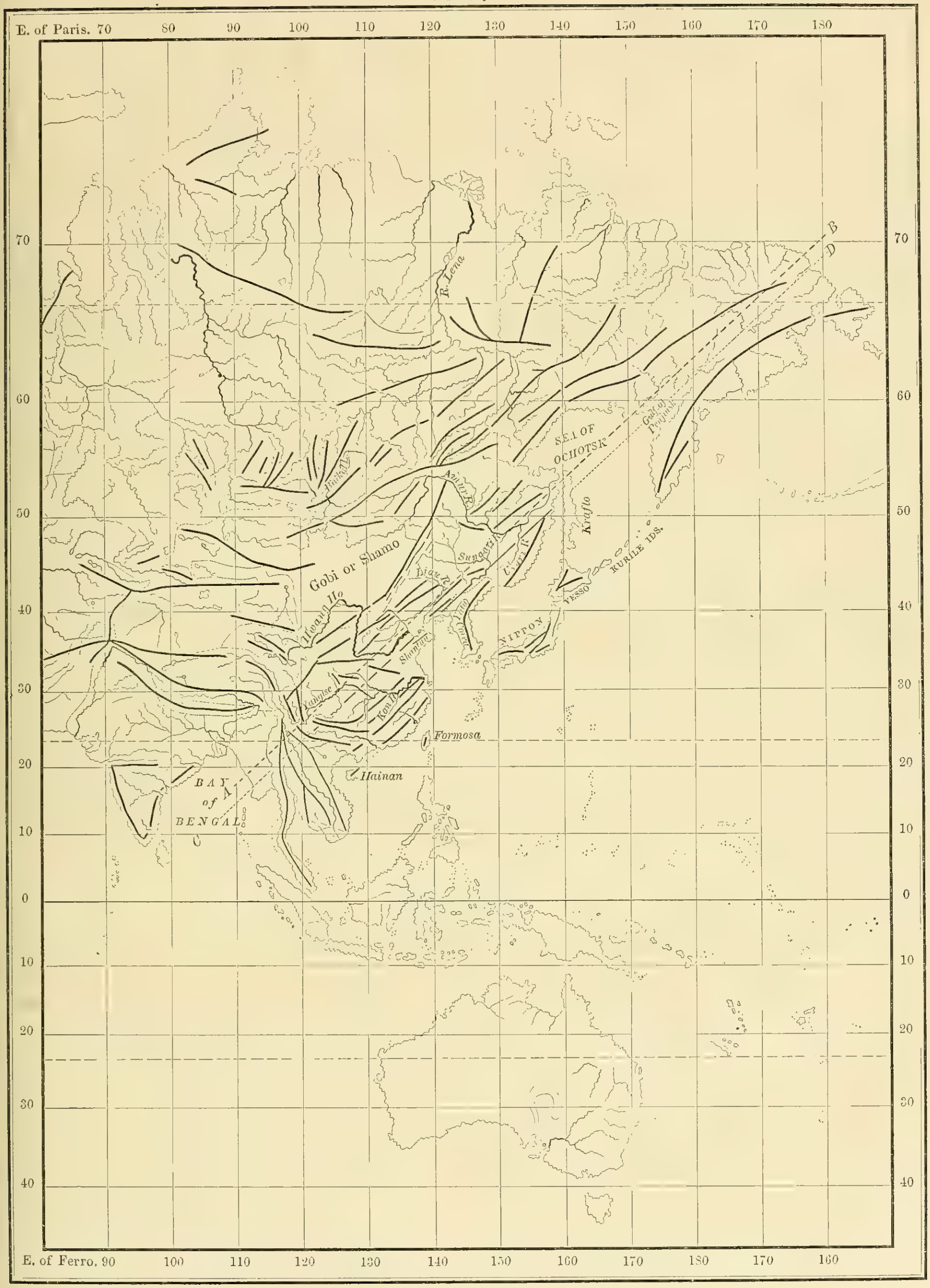
The broken line, A, B, indicates the great synclinal axis, and the dotted line, C, D, the main anticlinal axis.

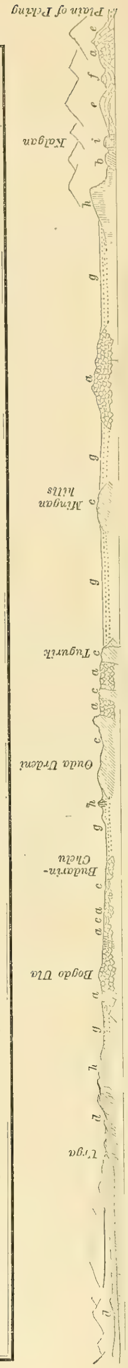
Section across the Table-Land of Central Asia, from the Plain of Peking to near Kiachta in Eastern Siberia.

See Chapter VIII.

The heights in the northern and southern thirds of the profile are from the measurements of Messrs. Fuss and v. Bunge ; those of the central third, being off from their route, are merely approximated.

Plate 7





a. Granite. b. Metamorphic Schists of N. China. c. Metamorphic Rocks of Mongolia. d. Metamorphic Rocks of Altai. e. Devon Limestone. f. Coal Measures. g. Steppe deposit. h. Basaltic and other Lavas. i. Trachytic Porphyry.

PLATE 8.

See Chapter IX.

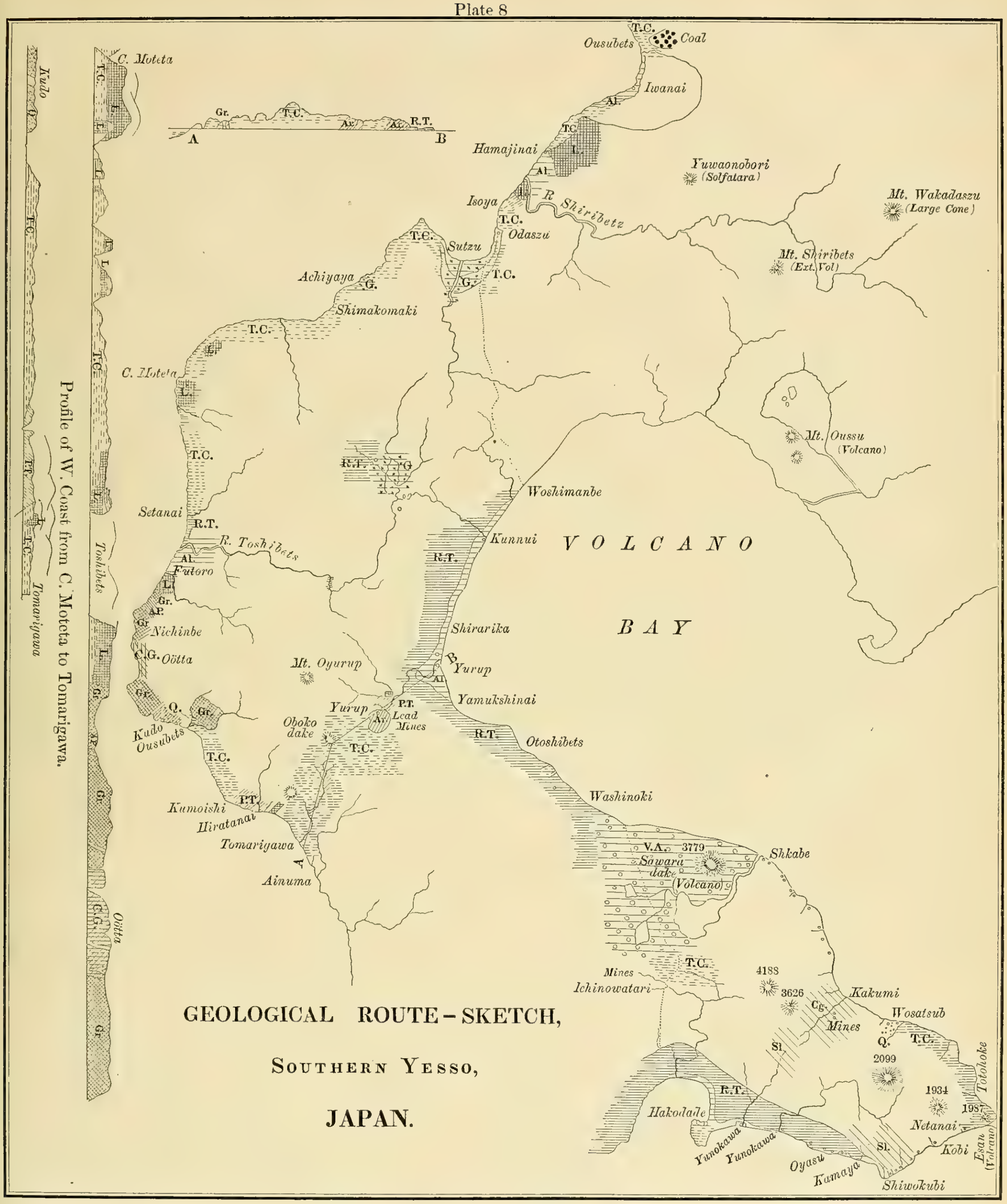
Geological Route-Sketch. Southern Yesso.

The geographical basis of this map is taken mainly from an unpublished Japanese survey of Yesso, in the Imperial Archives of the vice-royalty of Yesso.

Profile of the West Coast.

Section from the Japan Sea to Volcano Bay.

Plate 8



Al. *Alluvial and Beach.* V.A. *Volcanic Ashes.* G. *River Gravels.* R.T. *Recent Terraces.* L. *Lava.* T.C. *Tufa Conglomerate.* P.T. *Pumice Tufa.* ⁂ *Coal.*
Ar. *Metamorphic Argillite.* Q. *Quartzite.* Sl. Cg. *Clay Slates and Conglomerate.* C.G. *Conglomerate and Granulite*
A.P. *Aphanitic Rock.* Gr. *Granitic and Syenite Series.*

PLATE 9.

See Appendix No. 1.

Fossil Plants from the Chinese Coal-bearing Rocks.

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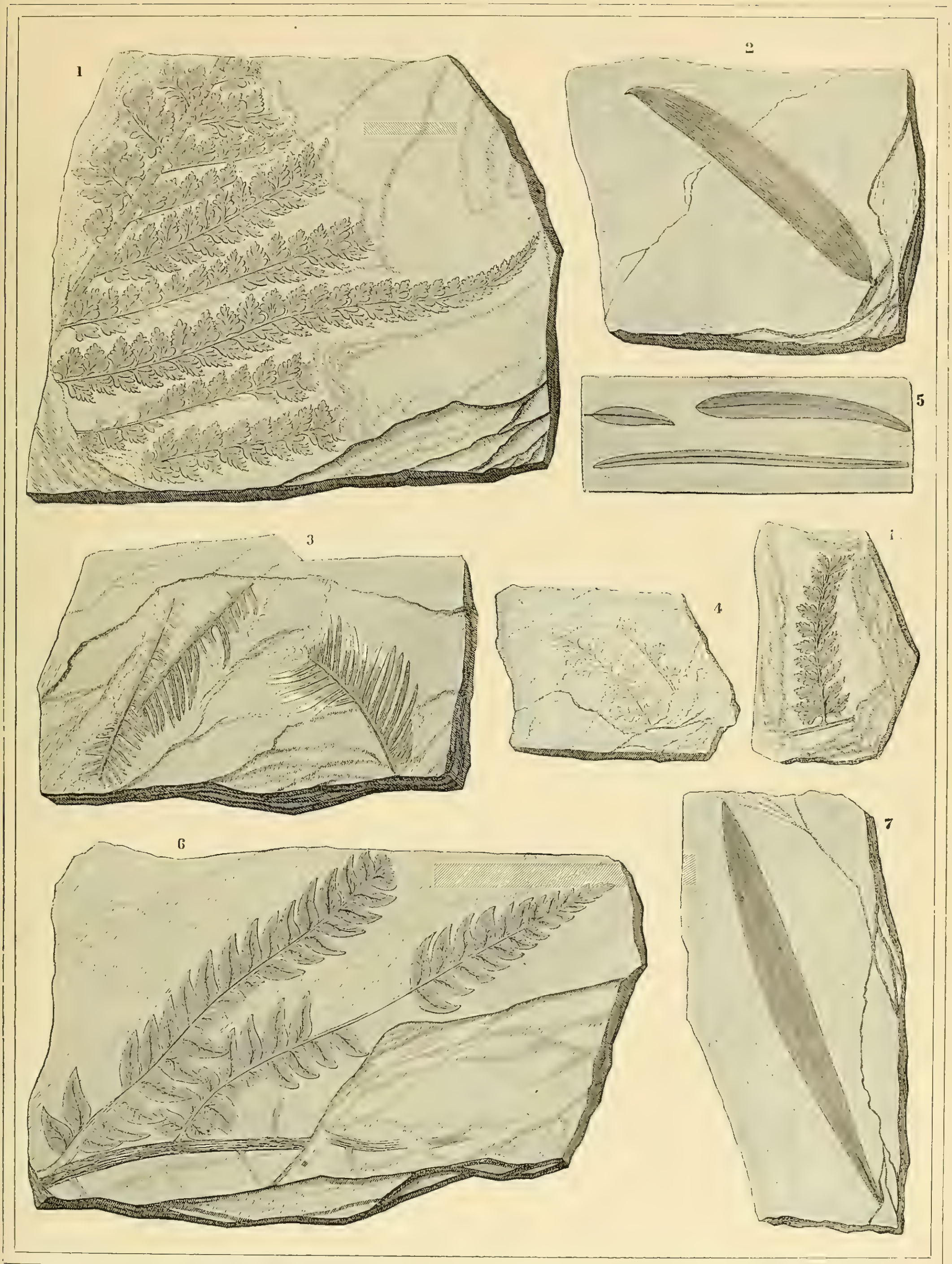
Plate 9



FOSSIL PLANTS FROM THE CHINESE COAL-BEARING ROCKS.

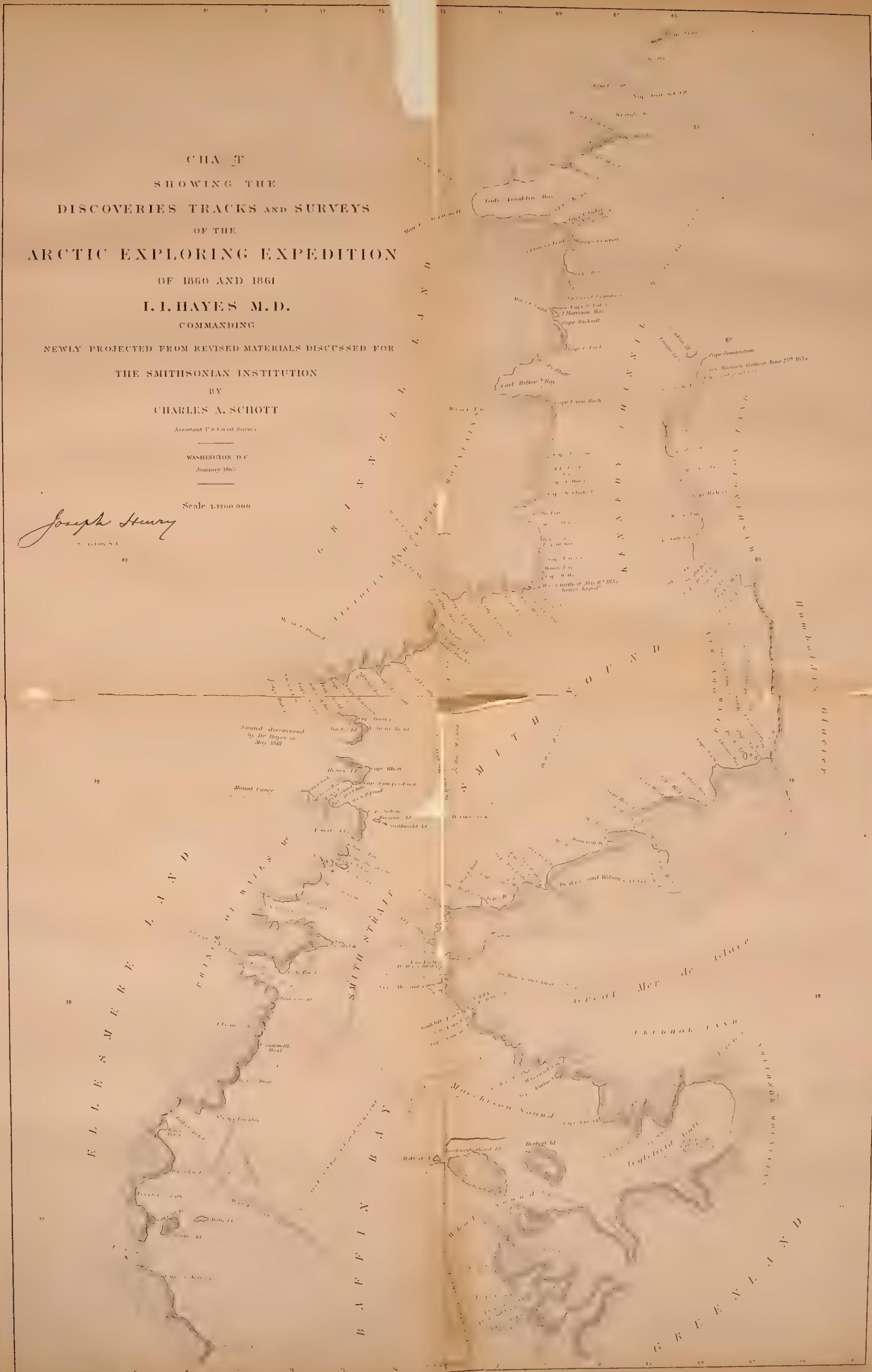


CHART
SHOWING THE
DISCOVERIES TRACKS AND SURVEYS
OF THE
ARCTIC EXPLORING EXPEDITION
OF 1860 AND 1861
I. I. HAYES M.D.
COMMANDING
NEWLY PROJECTED FROM REVISED MATERIALS DISCUSSED FOR
THE SMITHSONIAN INSTITUTION
BY
CHARLES A. SCHOTT
WASHINGTON D.C.
Scale 1:1200 000
Joseph Henry
SMITH SOUND
SMITH STRAIT
BAFFIN BAY
ELLESMERE LAND
GRINNELL LAND
GREENLAND
Humboldt Glacier
Great Mer de Glace
Sound discovered by Dr Hayes in May 1861
Mount Carey
Cape Constitution
Cape Back
Lady Franklin Bay
Kennedy Channel
Murchison Sound
Herbert Id
Northumberland Id
Cape Albert
Cape Isabella

SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE.

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PHYSICAL OBSERVATIONS

IN THE

ARCTIC SEAS.

BY

ISAAC I. HAYES, M.D.,

COMMANDING EXPEDITION.

MADE ON THE WEST COAST OF NORTH GREENLAND, THE VICINITY OF SMITH STRAIT AND THE WEST SIDE OF KENNEDY CHANNEL, DURING 1860 AND 1861.

REDUCED AND DISCUSSED

AT THE EXPENSE OF THE SMITHSONIAN INSTITUTION.

BY

CHARLES A. SCHOTT,

MEMB. AM. PHIL. SOC. PHILADELPHIA; ASSISTANT U. S. COAST SURVEY.

[ACCEPTED FOR PUBLICATION, FEBRUARY, 1865.]

PHILADELPHIA:
COLLINS, PRINTER, 705 JAYNE STREET.

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PLATES.

WOOD-CUTS.

INTRODUCTION.

The observations of which the record and results are given in the following pages were made during the expedition to the Arctic regions in 1860–61, under the command of Dr. Isaac I. Hayes. The principal objects of this expedition were to extend the exploration of Dr. Kane towards the north, and to make such observations of a scientific character as might tend to increase the existing knowledge of the Physical Geography, Meteorology, and Natural History of the region within the Arctic circle including the coasts and islands on either side of Smith's Straits.

The inception, organization, and equipment of the expedition were due to the energy and perseverance of Dr. Hayes, who succeeded in awaking a popular interest in the enterprise, and in obtaining the aid of scientific institutions and liberal individuals in carrying out his design. The larger part of the outfit was from voluntary contributions. The instruments were principally supplied by the Coast Survey, the Smithsonian Institution, and the Hydrographical Bureau of the Navy Department. The articles for collecting and preserving specimens of natural history were furnished by the Smithsonian Institution, the Academy of Natural Sciences of Philadelphia, and the Museum of Comparative Zoology at Cambridge, Mass. The original plan contemplated the employment of a small steamer and a schooner, but the means obtained were only sufficient to fit out a sailing vessel of 133 tons burthen, drawing eight feet of water. The party consisted of fifteen persons, exclusive of the commander, besides those engaged after the expedition arrived in Greenland. The astronomical, magnetical, and meteorological observations were principally under the direction of Mr. Augustus Sonntag, a native of Northern Germany, who had made himself favorably known by his scientific publications. He had accompanied Dr. Kane's expedition as astronomer and physicist, and, after his return, had made a magnetic and geographical survey in Mexico. He resigned the position of assistant in the Albany Observatory to join the expedition under Dr. Hayes, from which he was destined never to return.

The expedition left Boston harbor on the 9th of July, 1860, and, after sailing through a dense fog which continued seven days, or until after passing Cape Race, met with favorable winds which enabled it on the 30th of July to cross the Arctic circle. The first iceberg was seen July 23d, 8 P. M. Land was made on the 31st, and proved to be Disco Island. August 5th, at midnight, the explorers reached the Danish settlement Proven, on the western coast of Greenland. Disappointed in obtaining dogs, they put to sea again on the morning of August 12th, and on the same day were at Upernavik, the residence of the chief Danish trader. Here they

were detained four days in collecting dogs and procuring suitable garments of skins and furs to withstand the Arctic winter. Through the kindness of Mr. Hansteen, the governor, they obtained the services of three Esquimaux hunters, and also of a Dane as interpreter.

Leaving Upernavik, they were beset by an immense number of icebergs, some of them upwards of two hundred feet in height and a mile in length, the motion of which was principally due to the undercurrents, and therefore sometimes contrary to that of the wind. On the evening of August 21st they arrived at Tessuissak, also a Danish station, of which the geographical position was determined by Mr. Sonntag, where they obtained another supply of dogs.

From this place, they entered Melville Bay on the 23d of August. The wind had prevailed for several days from the eastward, and had apparently driven the ice towards the American side, opening before them a clear broad expanse of water. They did not meet with field ice until the 25th; through this they were so fortunate as to find an opening, and soon entered the northern water about twenty miles south of Cape Alexander, the jutting point on the Greenland side of Smith's Straits. This strait was entered on the 27th of August, but their efforts to find a navigable opening were interrupted by a heavy gale, which continued with great force for three days. It was not until after having been twice blown out that they effected a permanent lodgment in the straits on the second of September.

Failing to find an opening toward the west, they sought one higher up, near Cape Hatherton; but, when off Lyttleton Island, the schooner became so much damaged by collisions with the ice, that they were obliged to seek anchorage. They put to sea again on the 6th, but, failing to make headway, and the temperature having fallen to 12°, they were obliged to seek winter-quarters, which they found in Hartstene Bay, ten miles northeast of Cape Alexander. This was in a harbor to which the name of Port Foulke was given, in honor of one of the prominent patrons of the expedition. From subsequent observations this place was found to be in 78° 17′ 39″ north latitude, and longitude 73° 00′ 00″ west of Greenwich, twenty miles south of the latitude of Rensselaer Harbor, Dr. Kane's winter-quarters, and distant from it by the coast line about fifty-five st. miles.

In preparation for the winter, a house was built on shore to receive the stores, and the hold of the vessel was converted into a single room for the men. The deck was roofed over with boards brought from Boston for the purpose, and with these accommodations the ship's company lived in health and comfort during the winter. Game was found in abundance, the hunters rarely returning empty-handed. Reindeer in herds of ten and fifteen were frequently seen. The dogs, thirty in number, according to Esquimaux custom, were only fed every second day, and often devoured an entire reindeer at a single meal.

Soon after entering into winter-quarters an observatory was erected near the vessel, under the direction of Mr. Sonntag. It consisted of a wooden frame eight feet square and seven feet high, covered first with canvas, then with snow, and lined throughout with bear and deer skins. In this observatory the pendulum apparatus was vibrated for nearly a month; and on completing the series of observations with it, the magnetometer was substituted in its place. Near the observatory a

suitable shelter was also erected for the thermometers. These, which were mostly filled with spirits of wine, were in part a present from Mr. Tagliabue, of New York They were observed, with the other instruments, each hour during the whole twenty-four every seventh day, and three times a day in the interval. In addition to these observations, the temperature was noted every second hour by a thermometer suspended from a pole on the ice.

In the autumn, Dr. Hayes, in connection with Mr. Sonntag, made a survey of a glacier which had been named by Dr. Kane "My Brother John's Glacier," and which is in a valley near the head of the bay in which the vessel was wintered. It was nearly two miles from the sea, which it is gradually approaching; and in order to determine its rate of progress, a base line was measured along its axis, from either end of which angles were taken to fixed objects on the mountain on each side. These measurements were repeated after an interval of eight months, and the result indicated a downward movement of ninety-four feet.

The sun was absent one hundred and thirty days, and during that long period of darkness the whole party enjoyed remarkably good health. This was in a great measure due to habits of regularity as to exercise and cleanliness enjoined on every member of the expedition, as well as to the abundant supply of fresh food. With the advance of winter, however, there came a serious misfortune, which almost paralyzed further effort; a disease which for several years had prevailed throughout Greenland broke out among the dogs, and before the middle of December the number of the pack was reduced to eleven. As the plan of extending the exploration was based on the use of these animals, it was absolutely necessary, at whatever cost of labor or expense of means, to obtain another supply, and for this purpose Mr. Sonntag volunteered to venture on a journey across the ice to a settlement of Esquimaux on the other side of Whale Sound. He started on this perilous enterprise on the 22d of December, accompanied by a young Esquimaux, and furnished with a sled drawn by nine dogs. In attempting to cross a wide crack in the ice which had but lately been frozen over, he fell in, was thoroughly wetted, and, before he could reach a place of shelter, was so chilled as to become insensible, and he died soon after. This event, which cast a profound gloom over the whole party, was a great loss to science. Mr. Sonntag had received a thorough mathematical education, was well trained in the use of instruments of precision, and, had his life been spared, would have extended the series of observations, and would have thus added to the value of the materials obtained. Fortunately he had completed the pendulum experiments, the principal astronomical determinations, commenced the magnetic and meteorological observations, and trained the assistants in the use of instruments. After his death, the observations were continued, under the immediate direction of the commander, by Mr. Radcliff, assisted by Mr. Starr and Mr. Knorr.

Having, in the spring, obtained from a band of Esquimaux which visited the vessel a new supply of dogs, some of which also died, leaving but two teams of seven each, a journey was made to establish a depot of provisions at the north, for use during the contemplated explorations in the opening of summer. Upon this occasion, Van Rensselaer Harbor, the winter-quarters of Dr. Kane, was visited, but no

vestige of the vessel which he had left there was seen. It had probably drifted out to sea with the ice, and subsequently been crushed and sunk.

The principal expedition from the vessel, which at first consisted of all the available members of the company, started on the fourth of April. It was furnished with a life-boat twenty feet long on runners, two teams of dogs, and provisions for seven persons for five months, and an additional supply for six persons and one team for six weeks. The intention was to cross directly over the ice of Smith's Straits to the western shore, and thence to continue the exploration northward as far as circumstances would permit; but this plan was frustrated by the condition of the ice and open water, which compelled them to travel along the eastern shore. The ice in the strait did not, however, improve as they advanced, but was crowded into ridges and hummocks more extensive than had ever before been seen; and finally, after three weeks' trial, it was found impracticable to transport the boat, prepared expressly for exploration in the polar water, across the straits, and Dr. Hayes was reluctantly obliged to send it back with most of the party, reserving for the further exploration three picked companions, two sleds, and fourteen dogs. With this reduction of force, the perilous journey was continued; but the hummocks became worse, and although the distance was only about forty miles in a direct line from the western coast, fourteen days were consumed in the journey.

The route they pursued was nearly the same as that followed in 1854 by Dr. Hayes under the direction of Dr. Kane, and an opportunity was thus afforded to make some important additions and corrections to the sketch of the shore line which had formerly been given. It was found that a channel or sound opening westward from Smith's Straits, separated Ellesmere Land from Grinnell Land, and that in the mouth of this sound are two large islands, to one of which the name of Bache, and to the other that of Henry was given. On the 12th of May Kennedy Channel was entered and the coast followed as it trends nearly due north to Ritter Bay. This point was reached on the 16th, when two of the party became exhausted by fatigue, and the exploration was continued for three days longer by Dr. Hayes and his assistant, Mr. George F. Knorr, and reached, May 18th, the latitude 81° 37′, about forty-one nautical miles beyond the limit of exploration under Dr. Kane and on the opposite side of the channel. To the highest point actually attained the name of Cape Lieber was given, and that of Church to a remarkable peak in the vicinity. On the north of Cape Lieber there opened a large bay, to which the name of Lady Franklin had been assigned by Kane; also on the north were seen a headland called Cape Beechey, and beyond another high point which was named, in honor of His Majesty the King of Denmark, Cape Frederick VII., and still farther in the distance a third projecting point was observed, which was designated Cape Union.

Returning upon the same track, the expedition reached the vessel after an absence of fifty-nine days, only seven dogs being alive, rendering further exploration in this way impracticable. The remainder of the time until the vessel was released from the ice was devoted to such surveys as could be made in the vicinity of Port Foulke, and the continuance of the observations of physical phenomena.

They were joined by a tribe of Esquimaux inhabiting the coast between Smith's

Strait and Cape York, numbering in all about eighty souls, who built snow-houses in the vicinity of the vessel, and maintained themselves by hunting the walrus and seal.

They sailed from the winter harbor on the 14th of July, and after much difficulty reached the west coast ten miles below Cape Isabella, and from an elevation of about six hundred feet Dr. Hayes obtained a view to the northward. In that direction the ice was everywhere unbroken, and as it did not appear probable that he could obtain for the schooner another harbor farther north, and as only five dogs remained without means of obtaining a new supply, he was reluctantly obliged to abandon the field, and direct his course homeward, trusting to be able at an early day to renew the exploration with a small steamer and under other more favorable conditions.

Entering Whale Sound, an excellent opportunity was presented for delineating the shore-line of that inlet; through a clear atmosphere the land from the north around to the south could be traced, thus proving the inlet to be a deep gulf which, in honor of the discoverer, was named the Gulf of Inglefield. Leaving Whale Sound and proceeding southerly, the survey was complete of north Baffin's Bay from Cape Alexander to Granville Bay. After laboriously working the way through "pack ice" for one hundred and fifty miles they entered the southern waters, and reached Upernavik on the 14th of August, and Disco Island on the 31st of August, being at both places kindly and hospitably received by the Danish officials.

At Godhaven they were informed by Inspector Olrik that he had received orders from his government to afford such aid to the expedition as was in his power, thus exhibiting that characteristic generosity and intelligent appreciation of science which marked its action towards all previous expeditions of a similar character.

Leaving Greenland they arrived in Boston, after a stormy passage, on the 23d of October, having been absent 15 months and 13 days.

During the whole cruise effort was constantly made to obtain specimens of geology and natural history, and though the party was small, valuable collections were obtained, embracing dredgings, plants, birds, and a large number of skulls of Esquimaux.

On the return of the expedition the records of the observations, excepting those relating to natural history, were given in charge to the Institution for reduction, discussion, and subsequent publication. They were placed in the hands of Mr. Chas. A. Schott, of the U. S. Coast Survey, and have been prepared by him for the press at the expense of the Smithsonian fund.

The foregoing sketch has been taken principally from the report of the lectures given by Dr. Hayes before the Institution in 1861. He has since, however, published a narrative in full, from which a minute account can be obtained of all the events of the expedition.

JOSEPH HENRY,
Secretary S. I.

SMITHSONIAN INSTITUTION.

PART I.

ASTRONOMICAL OBSERVATIONS.

RECORD AND RESULTS

OF

ASTRONOMICAL AND GEODETIC OBSERVATIONS.

General Remarks.—The Arctic explorations made under the direction of Dr. Isaac I. Hayes, principally comprise the west coast of Smith Strait and Kennedy Channel, the existence of which had previously become known through the expedition under Dr. Kane, in the years 1853, '54, '55.

The scientific materials obtained by the expedition and referred to me for reduction and discussion by Professor Henry, Secretary of the Smithsonian Institution, are presented under the general heads of astronomical, magnetic, tidal, and meteorological observations.

The observations, especially the meteorological, are discussed on the same general plan as that adopted in the discussion of those of the expedition under Dr. E. K. Kane,[1] and also that under Sir J. L. McClintock,[2] as published by the Smithsonian Institution. The results, therefore, admit of the strict comparisons which have been made whenever practicable, and which give an additional interest and value to the series of publications of which this forms a part.

The present division under the title of Astronomical and Geodetic Observations, contains the determination of geographical positions, the results of surveys, and the pendulum experiments for relative force of gravity. Connected with this part is a large chart embracing the region of the exploration under Dr. Kane and that under Dr. Hayes, constructed from the additional materials collected by the latter, and also a smaller chart of the vicinity of Port Foulke, from original surveys.

The greater and more valuable portion of the observations was made by Mr. August Sonntag, astronomer and physicist to the expedition, and second in command. By his early death the expedition sustained a great loss, and we have espe-

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[1] Smithsonian Contributions to Knowledge: Magnetical, Meteorological, Astronomical, and Tidal Observations in the Arctic Seas, by Elisha Kent Kane, M. D., U. S. N., made during the second Grinnell expedition in 1853, 1854, and 1855; reduced and discussed by Charles A. Schott. Four parts, separately published in 1858, 1859, and 1860.

[2] Smithsonian Contributions to Knowledge: Meteorological Observations in the Arctic Seas, by Sir Francis L. McClintock, R. N., made in Baffin's Bay and Prince Regent's Inlet, in 1857, 1858, and 1859; reduced and discussed by Charles A. Schott. May, 1862.

cially to regret the scanty material for the determination of the longitude of Port Foulke. It was also his intention to have the pendulum experiments repeated during the following warm season.

The expedition was supplied with the necessary instruments; among these may be mentioned a prismatic reflecting circle, a Würdemann sextant, a vertical circle, and theodolite, all contributed by Prof. A. D. Bache; there were also three mean time (box) chronometers, one of these (No. 2007) an eight day chronometer. One of the chronometers was purchased from Willard, one hired from Bond, and one was lent free of cost by the brothers Negus; besides these Dr. Hayes purchased a pocket chronometer from Bond & Son; the pendulum was made by the same firm.

Reduction of the Observations.—The astronomical data required in the reduction were taken from the "American Ephemeris and Nautical Almanac."

All mere logarithmic work will be suppressed, but such intermediate results will be given which assist in forming a proper estimate of the value of the observations and of their treatment.

Separate results are in all cases preferred, unless the increased labor of computation counterbalances the advantage of comparability of individual results. They permit the recognition and consequent rejection of any defective observation in the series, and at the same time furnish the means of estimating or computing the probable uncertainty to which the final result may be subject. This, however, does not exclude the combination of a few readings to a mean reading or the arrangement of individual observations into groups, provided the interval of time is sufficiently short for second differences to have any appreciable effect. We may thus combine, in a measure, the advantages of the two methods.

The refractions have been computed from the tables in Captain Lee's "Collection of tables and formulæ, etc." They are Ivory's, and were considerably extended so as to meet the requirements of an arctic climate. I have preferred them to Bessel's, principally on account of their greater facility of application; they give a slightly higher value for very small altitudes.

Temperatures are recorded on Fahrenheit's scale, and the readings of the barometer are noted in inches and fractions of inches.

Mr. Sonntag had made preliminary computations of his observations which greatly facilitated the present reduction. It is to be understood that the observations were made by him, unless otherwise stated.

GEOGRAPHICAL POSITIONS.

Pröven, North Greenland, Station near the Governor's House.

Observations for time, August 6th (A. M. 7th), 1860.

Double altitudes of the sun with Würdemann's sextant.

Index[1] $\begin{cases} -32' \ 5'' \\ +31 \ 35 \end{cases}$ Correction —15″

Pocket chronometer	$2\overline{\odot}$	Pocket chronometer	$2\underline{\odot}$
$8^h\ 06^m\ 10^s$	57° 18′ 00″	$8^h\ 09^m\ 56^s$	56° 41′ 35″
06 54	23 10	10 27	44 20
07 36	28 20	11 17	50 20
	$2\underline{\odot}$		$2\overline{\odot}$
8 08 19	56 30 20	8 11 57	57 57 10
08 55	34 15	12 23	58 01 00
09 21	37 05	13 09	06 00

Temp. + 48° F., pressure $29^{in}.80$ at + 62 F. Index $\begin{cases} -32' \ 20'' \\ +31 \ 25 \end{cases}$ Correction —27″.5

$$\left.\begin{array}{l} \text{Let } \phi = \text{latitude} \\ \quad h = \text{altitude} \\ \quad \delta = \text{declination} \\ \quad t = \text{hour angle} \end{array}\right\} \text{then} \quad \cos t = \frac{\sin h - \sin \phi \sin \delta}{\cos \phi \cos \delta}$$

Approximate latitude 72° 23′, approximate longitude $3^h\ 42^m$ west of Greenwich. The first column of the following table contains the mean chronometer time T, the second the altitude corrected for index error, refraction, parallax (in altitude), and semi-diameter. The refraction was computed for the first and last, and interpolated for the middle times. The third column contains the hour angle computed by the above expression; converting t into time and applying the equation of time, the chronometer correction ΔT was found as given in the last column. A $\begin{cases} + \\ - \end{cases}$ sign indicates chronometer $\begin{cases} \text{slow} \\ \text{fast} \end{cases}$ on local time; $\begin{cases} - \\ + \end{cases}$ indicates $\begin{cases} \text{gaining} \\ \text{losing} \end{cases}$ rate. For the first and last set $r = -1'\ 45''.9$ $\quad r_1 = 1'\ 44''.7$ $\quad \pi_1 = +\ 7''.5$ and $\delta = +\ 16°\ 18'\ 8''$ for the middle.

T	h		ΔT
$8^h\ 6^m\ 53^s.3$	28° 23′ 56″	—44° 15′ 13″	$+1^h\ 01^m\ 33^s$
8 8 51.7	28 30 55	—43 44 43	36
8 10 33.3	28 36 41	—43 19 18	36
8 12 29.7	28 43 05	—42 50 52	34
			Mean, +1 01 34.7

[1] To the reading *off* the arc I shall give the sign +, to that *on* the arc the sign —, in order to obtain at once the index correction. In the record the observer always notes the index *error* and the *correction* has therefore the opposite sign; in this paper the sign was at once changed. This note applies to the sextant as well as to the reflecting circle.

Double altitudes of the sun with reflecting circle.

$$\text{Index}\begin{cases}+32'\ 10'' & -30'\ 40'' \\ +32\ \ 40 & -30\ \ 40\end{cases}, \text{ correction } +52''.5$$

Pocket chronometer.	$2\overline{\odot}$	Pocket chronometer.	$2\underline{\odot}$
8^h 20^m 51^s	58° 55′ {20″ / 30}	8^h 25^m 03^s	58° 19′ {60″ / 50}
8 21 48	59 01 {60 / 50}	8 25 40	58 23 {40 / 20}
	$2\underline{\odot}$		$2\overline{\odot}$
8 23 18	58 {08 40 / 07 40}	8 27 42	59 39 {40 / 20}
8 24 09	58 14 {40 / 10}	8 28 18	59 42 {60 / 40}

$$\text{Index}\begin{cases}+32'\ 30'' & -30'\ 40'' \\ +32\ \ 40 & -30\ \ 20\end{cases}, \text{ correction } +62''.5$$

For the first and last set $r = -1'\ 42''.8$ $r_1 = -1'\ 41''.1$ $\pi_1 = +7''.5$ and $\delta = +16°\ 17'\ 57''$ for the middle.

T	h	t	ΔT
8^h 21^m $19^s.5$	29° 12′ 25″	−40° 37′ 33″	$+1^h$ 01^m 37^s
8 23 43.5	29 20 20	−40 00 48	40
8 25 21.5	29 25 33	−39 36 12	40
8 28 00	29 33 41	−38 57 29	37
		Mean,	+1 01 38.5

Observations for time, August 7th.

Double altitudes of the sun with reflecting circle and sextant.

Index correction +1′ 9″ Reflecting circle.

Pocket chronometer.	$2\underline{\odot}$	Pocket chronometer.	$2\overline{\odot}$
2^h 41^m 58^s	51° 04′ {40″ / 40}	2^h 46^m 23^s	51° 32′ {40″ / 20}
2 42 47	50 57 {30 / 30}	2 47 26	51 23 {00 / 20}
	$2\overline{\odot}$		$2\underline{\odot}$
2 44 17	51 48 {40 / 50}	2 48 24	50 13 {10 / 20}
2 45 17	51 41 {20 / 20}	2 49 09	50 07 {20 / 00}

$$\text{Index}\begin{cases}+31'\ 20'' \\ -32\ \ 00\end{cases} \text{ correction } 20''$$

Sextant.

Pocket chronometer.	$2\overline{\odot}$	Pocket chronometer.	$2\underline{\odot}$
2^h 56^m 41^s	50° 09′ 40″	2^h 58^m 52^s	48° 48′ 05″
57 18	05 00	2 59 40	42 00
57 50	00 40	3 00 09	37 50

T = + 51° B = $29^{in}.8$ at 60° $$\text{Index}\begin{cases}+31'\ 20'' \\ -32\ \ 05\end{cases} \text{ correction } -22''.5$$

$r = -2'\ 01''$ $r_1 = -2'\ 07''$ $\pi_1 = +8''$ $\delta = +16°\ 13'\ 31''$ and $+16°\ 13'\ 18''$ for first and last set.

T	h	t	ΔT
2^h 42^m $22^s.5$	25° 45′ 03″	54° 38′ 41″	$+1^h$ 01^m 37^s
2 44 47	25 35 25	55 15 07	38
2 46 54.5	25 26 49	55 47 34	40
2 48 46.5	25 19 34	56 14 31	36
2 57 16.3	24 44 38	58 23 43	43
2 59 33.7	24 34 59	58 58 43	46
		Mean,	+1 01 40.0

Observations for time, August 7th (A. M. 8th).

Double altitudes of the sun with reflecting circle.

Index $\left\{\begin{matrix} +32' & 30'' & -30' & 0'' \\ +32 & 40 & -29 & 40 \end{matrix}\right\}$, correction $+1'\ 22''.5$

Pocket chronometer.	$2\underline{\odot}$	Pocket chronometer.	$2\overline{\odot}$
$8^h\ 21^m\ 05^s$	$57°\ 21'\left\{\begin{matrix}20''\\50\end{matrix}\right.$	$8^h\ 26^m\ 43^s$	$59°\ 01'\left\{\begin{matrix}20''\\20\end{matrix}\right.$
8 22 16	$57\ \ 30\left\{\begin{matrix}30\\00\end{matrix}\right.$	8 27 39	$59\ \ 06\left\{\begin{matrix}20\\40\end{matrix}\right.$
	$2\overline{\odot}$		$2\underline{\odot}$
8 23 35	$58\ \ 41\left\{\begin{matrix}00\\10\end{matrix}\right.$	8 28 36	$58\ \ 10\left\{\begin{matrix}10\\00\end{matrix}\right.$
8 25 14	$58\ \ 51\left\{\begin{matrix}60\\30\end{matrix}\right.$	8 29 15	$58\ \ 13\left\{\begin{matrix}50\\40\end{matrix}\right.$

T = + 50°, B = $29^{in}.80$ at 63° Index $\left\{\begin{matrix} +32' & 30'' & -30' & 30'' \\ +32 & 40 & -30 & 20 \end{matrix}\right\}$, correction $+1'\ 5''$

hence: $r = -1'\ 45''.3$ $r_1 = -1'\ 43''.6$ $\pi_1 = +7''.4$ and $\delta = +16°\ 00'\ 53''$ for the middle.

T	h	t	ΔT
$8^h\ 21^m\ 40^s.5$	28° 57′ 46″	—40° 28′ 40″	$+1^h\ 01^m\ 44^s$
8 24 24.5	29 06 25	—39 48 07	42
8 27 11	29 15 11	—39 06 40	41
8 28 55.5	29 20 47	—38 39 46	44
		Mean,	+1 01 42.7

Double altitudes of the sun with reflecting circle. Aug. 8th.

Index $\left\{\begin{matrix} +32' & 20'' & -30' & 40'' \\ +32 & 30 & -30 & 20 \end{matrix}\right\}$, correction $+57''.5$

Pocket chronometer.	$2\underline{\odot}$	Pocket chronometer.	$2\overline{\odot}$
$2^h\ 19^m\ 00^s$	$53°\ 26'\left\{\begin{matrix}40''\\30\end{matrix}\right.$	$2^h\ 22^m\ 22^s$	$54°\ 04'\left\{\begin{matrix}40\\40\end{matrix}\right.$
2 19 49	$53\ \ 20\left\{\begin{matrix}40\\50\end{matrix}\right.$	2 23 09	$53\ \ 58\left\{\begin{matrix}50\\60\end{matrix}\right.$
	$2\overline{\odot}$		$2\underline{\odot}$
2 20 43	$54\ \ 17\left\{\begin{matrix}20\\00\end{matrix}\right.$	2 24 02	$52\ \ 49\left\{\begin{matrix}20\\00\end{matrix}\right.$
2 21 33	$54\ \ 10\left\{\begin{matrix}40\\30\end{matrix}\right.$	2 24 36	$52\ \ 44\left\{\begin{matrix}40\\60\end{matrix}\right.$

T = +52°, B = $29^{in}.80$ at 62° Index $\left\{\begin{matrix} +32' & 40'' & -30' & 30'' \\ +32 & 30 & -30 & 10 \end{matrix}\right\}$, correction $+1'\ 07''.5$

hence: $r = -1'\ 54''.3$ $r_1 = -1'\ 55''.8$ $\pi_1 = +7''.6$ and $\delta = +15°\ 56'\ 38''$ for the middle.

T	h	t	ΔT
$2^h\ 19^m\ 24^s.5$	26° 56′ 24″	+48° 55′ 03″	$+1^h\ 01^m\ 33^s$
2 21 08	26 49 54	+49 21 09	34
2 22 45.5	26 43 51	+49 45 34	34
2 24 19	26 38 02	+50 08 40	33
		Mean,	+1 01 33.5

Recapitulation of Correction of Pocket Chronometer on Pröven Time.

	ΔT
August 7th, 9 A. M.	$+1^h\ 01^m\ 34^s.7$
" 7th, 9 A. M.	38.5
" 7th, 4 P. M.	40.0
" 8th, 9 A. M.	42.7
" 8th, 3 P. M.	33.5
Mean,	+1 01 37.9

Observations for latitude, August 7th. Reflecting circle.
Circummeridian altitudes of the sun.

Index $\left\{\begin{matrix} +32' & 50'' & -30' & 50'' \\ +32 & 30 & 30 & 00 \end{matrix}\right\}$, correction $+1'\ 07''.5$

Pocket chronometer.	$2\overline{\odot}$	Pocket chronometer.	$2\underline{\odot}$
$10^h\ 50^m\ 07^s$	$68°\ 15'\ \left\{\begin{matrix}50''\\40\end{matrix}\right.$	$11^h\ 02^m\ 55^s$	$67°\ 17'\ \left\{\begin{matrix}10''\\20\end{matrix}\right.$
10 51 32	$68\ \ 17\ \left\{\begin{matrix}20\\40\end{matrix}\right.$	11 04 20	$67\ \ 17\ \left\{\begin{matrix}00\\10\end{matrix}\right.$
	$2\underline{\odot}$		$2\overline{\odot}$
10 54 02	$67\ \ 14\ \left\{\begin{matrix}60\\30\end{matrix}\right.$	11 05 52	$68\ \ 19\ \left\{\begin{matrix}30\\30\end{matrix}\right.$
10 55 10	$67\ \ 15\ \left\{\begin{matrix}50\\30\end{matrix}\right.$	11 07 08	$68\ \ 19\ \left\{\begin{matrix}20\\30\end{matrix}\right.$

T = +54°, B = $29^{in}.80$ at 60° Index $\left\{\begin{matrix} +32' & 20'' & -30' & 40'' \\ +32 & 20 & -30 & 40 \end{matrix}\right\}$, correction $+50''$

Intermediate set of observations with W.'s sextant.

Index $\left\{\begin{matrix} +31' & 05'' & -32' & 00'' \\ +31 & 20 & -32 & 15 \end{matrix}\right\}$ Correction $-27''.5$

Pocket chronometer.	$2\underline{\odot}$	Pocket chronometer.	$2\overline{\odot}$
$10^h\ 56^m\ 57^s$	$67°\ 16'\ 20''$	$11^h\ 09^m\ 31^s$	$68°\ 19'\ 10''$
57 56	17 10	10 36	18 20
58 47	17 0	11 20	18 20
	$2\overline{\odot}$		$2\underline{\odot}$
10 59 47	68 19 30	11 12 32	67 14 50
11 00 52	19 20	13 42	14 15
11 01 41	20 15	14 27	14 10

We have, according to Gauss' method of reduction (Chauvenet's Spherical and Practical Astronomy, Vol. I, p. 244), with the assumed longitude $3^h.703$ west of Greenwich:—

δ = sun's declination at apparent noon . . . = $+16°\ 16'\ 05''.4$

δ_1 = " " mean " . . . = $+16\ \ 16\ \ 09.2$

$\Delta\delta$ = hourly increase of declination, + for sun moving northward = $-42^s.3$

ζ_1 = meridian zenith distance = $\phi-\delta = 56°\ 06'\ 55''$

ϑ = hour angle of maximum altitude (in seconds of the chronometer) = $[9.40594]\ \frac{\Delta\delta}{A}$; the angular brackets include a logarithm.

$A = k^1\ \frac{\cos\phi\cos\delta}{\sin\zeta_1}$ for the sun and a mean time chronometer.

k^1 = a tabular number having for its argument $\delta T-\delta E$, that is, the daily rate of the chronometer less the daily *increase* in the equation of time E, which is positive when additive to apparent time.

$\delta E = -7^s.4$, $\delta T = +1^s.5$, $k_1 = [0.00009]$, $A = +0.35004$ and $\vartheta = -30^s.8$.

$\phi = \zeta - Am + \delta_1 + y$ where m is a tabular number depending on the hour angle t^1 reckoned from the instant the sun reaches its maximum altitude, $-Am$ the reduction to the observed zenith distance and $y = A\ \frac{2\sin^2\frac{1}{2}\vartheta}{\sin 1''} = -0.^s2$

Mean time of apparent noon	$+5^m$ $25^s.8$
Chronometer error	-1 01 39.3
Chronometer time of apparent noon	11 03 46.5
ϑ	-30.8
Chronometer time of sun's maximum altitude . . .	11 03 15.7

From reflecting circle, with $r = -1' \; 24''.6$ $\quad r_1 = -1' \; 24''.5$ $\quad \pi_1 = +7''$

T	h	mA	$h + mA$
10^h 50^m $49^s.5$	33° 51′ 41″	107″	33° 53′ 28″
10 54 36	33 52 36	52	28
11 03 37.5	33 53 35	0	35
11 06 30	33 53 07	7	14
			33 53 26

From sextant, with $r = -1' \; 26''.2$ $\quad r_1 = -1' \; 26''.2$ $\quad \pi_1 = +7''$

T	h	mA	$h + mA$
10^h 57^m $53^s.3$	33° 52′ 41″	20″	33° 52′ 61″
11 00 46.7	33 52 31	4	35
11 10 29	33 51 59	36	35
11 13 33.7	33 51 29	72	41
			33 52 43

Mean, by circle and sextant	33 53 05
$90 + \delta_1 + y$	106 16 09
ϕ	72 23 04

This latitude was also determined by Kane, July 19, 1853, A. Sonntag, observer.[1] I found 72° 22′ 58″.

The mean of the two determinations, or 72° 23′ 01″, has been adopted as a reliable latitude of the Governor's house at Pröven.

Observations for longitude, August 7th.

Chronometer comparisons; $\Delta T = +1^h \; 01^m \; 37^s.9$ for pocket chronometer.

Chronometer.		Pocket chronometer.	Mean time.	ΔT
2007	5^h 13^m	0^h 30^m $47^s.6$	1^h 32^m $25^s.5$	-3^h 40^m $34^s.5$
1062	5 14	0 31 21.6	1 32 59.5	-3 41 00.5
740	5 15	0 32 29.5	1 34 07.4	-3 40 52.6

(N. B. Another comparison on the 6th shows the correctness of the above.)

The correction and rate of the three chronometers were determined at Boston, July 7, 1860, by Williard, as follows:—

Chronometer.	ΔT at Boston on Greenwich time.	Boston rate δT	ΔT on Greenw. time August 7.	ΔT on Pröven time August 7.	Long. of Pröven west of Greenwich.
2007	$+1^m$ $35^s.3$	$+0^s.4$	$+1^m$ $47^s.7$	-3^h 40^m $34^s.5$	3^h 42^m $22^s.2$
1062	$+0$ 57.0	$+0.2$	$+1$ 03.2	-3 41 00.5	3 42 03.7
740	$+1$ 14.7	0.0	$+1$ 14.7	-3 40 52.6	3 42 07.3
				Mean . . .	3 42 11.1

The longitude determined approximately by Kane, in 1853, was $3^h \; 42^m \; 30^s$ (see p. 41 of his Astronomical Observations).

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[1] Smithsonian Contributions, 1860: Kane's Astronomical Observations in the Arctic Seas, p. 36.

Port Foulke, OBSERVATORY, SMITH STRAIT.

Port Foulke, a short distance to the northward and eastward of Cape Alexander, Smith Strait, was the winter quarters of the expedition during 1860–1861; the astronomical and magnetic observatory is situated at the head of the bay.

Observations for time. September 9th, 1860.

Double altitudes of the sun with reflecting circle.

Index $\left\{\begin{array}{llll} +32' & 50'' & -30' & 20'' \\ +32 & 50 & -30 & 10 \end{array}\right\}$ Correction +1′ 17″.5

Pocket chronometer.	$2\underline{\odot}$	Pocket chronometer.	$2\overline{\odot}$
4^h 09^m 01^s	24° 23′ {00″ / 00}	4^h 17^m 15^s	24° 45′ {50″ / 50}
9 55	24 18 {50 / 20}	18 07	24 41 {20 / 20}
11 01	24 13 {30 / 10}	19 04	24 {37 10 / 36 30}
	$2\overline{\odot}$		$2\underline{\odot}$
4 13 21	25 03 {40 / 30}	4 21 10	23 22 {50 / 40}
14 14	25 00 {30 / 30}	22 06	23 18 {40 / 30}
15 04	24 56 {20 / 10}	23 14	23 13 {30 / 20}

T = +26°.0, B = 29^{in} 80 at 62° Index $\left\{\begin{array}{llll} +33' & 0'' & -31' & 00'' \\ +33 & 0 & -30 & 40 \end{array}\right\}$ Correction +1′ 05″

Assumed latitude 78° 17′ 39″, assumed longitude 4^h.865 west of Greenwich.

Reducing these observations by the formula

$$sin\ \tfrac{1}{2}t = \sqrt{\left(\frac{sin\ \frac{1}{2}\left[\zeta + (\phi - \delta)\right]\ sin\ \frac{1}{2}\left[\zeta - (\phi - \delta)\right]}{cos\ \phi\ cos\ \delta}\right)}$$

we have for each set: $r = -4'\ 32''.7$ $r_1 = -4'\ 40''.0$ $\pi_1 = +\ 8''.3$

T	ζ	δ	t
4^h 12^m $06^s.0$	77° 44′ 12″	+5° 00′ 52″	+51° 08′ 18″
4 20 09.3	78 04 02	+5 00 45	+53 09 04

Converting into mean time and comparing with the chronometer time, we find the chronometer corrections:—

—50^m 35^s.0 and from second set
—50 35.2

ΔT = —50 35.1

Observations for time, September 9th (10th A. M.). Strong wind, affecting the artificial horizon.

Double altitudes of the sun, with reflecting circle.

Index $\left\{\begin{array}{llll} +32' & 40'' & -31' & 00'' \\ +33 & 10 & -30 & 30 \end{array}\right\}$ Correction +1′ 5″

Pocket chronometer.	$2\underline{\odot}$	Pocket chronometer.	$2\overline{\odot}$
10^h 8^m 42^s	26° 55′ {30″ / 00}	10^h 14^m 29^s	28° 22′ {20″ / 00}
9 25	26 59 {60 / 40}	15 02	28 24 {40 / 00}
10 07	27 02 {50 / 40}	15 42	28 26 {40 / 30}
	$2\overline{\odot}$		$2\underline{\odot}$
10 11 02	28 09 {10 / 00}	10 16 50	27 28 {40 / 20}
11 43	28 12 {20 / 00}	17 28	27 30 {50 / 40}
12 20	28 14 {40 / 20}	18 33	27 34 {60 / 40}

$T = +23°.5$, $B = 29^{in}.50$ at $68°$ Index $\begin{cases} +32'\ 40'' & -30'\ 50'' \\ +32\ \ 50 & -30\ \ 30 \end{cases}$ Correction $+1'\ 3''$

$r = -4'\ 02''.6$ $r_1 = -3'\ 59''.3$ $\pi_1 = +8''.3$

T	ζ	δ	t	E	ΔT
$10^h\ 10^m\ 33.^s2$	76° 15′ 33″	+4° 43′ 48″	−39° 08′ 12″	$-3^m\ 17.^s7$	$-0^h\ 50^m\ 23.^s7$
10 16 20.7	76 04 22	+4 43 42	−37 41 00	−3 17.8	−0 50 22.5

These observations were no doubt affected by the strong wind, the result will therefore not be used.

Observations for time, September 10.

Double altitudes of the sun, with reflecting circle.

Index $\begin{cases} +32'\ 40'' & -30'\ 40'' \\ +32\ \ 40 & -30\ \ 20 \end{cases}$ Correction $+1'\ 5''$

Pocket chronometer	2☉	Pocket chronometer	2☉
$3^h\ 38^m\ 20^s$	25° 55′ {20″, 00}	$3^h\ 42^m\ 56^s$	26° 38′ {20″, 00}
39 00	25 51 {60, 30}	43 33	26 35 {40, 10}
39 36	25 49 {30, 20}	44 14	26 32 {40, 40}
	2☉̄		2☉̲
3 40 36	26 48 {30, 10}	3 45 07	25 25 {10, 20}
41 12	26 45 {40, 40}	45 40	25 22 {60, 50}
41 48	26 42 {40, 40}	46 22	25 19 {20, 00}

$T = +27°.5$, $B = 29^{in}.50$ at $64°$ Index $\begin{cases} +32'\ 40'' & -31'\ 00'' \\ +32\ \ 50 & -30\ \ 40 \end{cases}$ Correction $+57''$

hence: $r = -4'\ 12''.2$ $r_1 = -4'\ 15''.4$ $\pi_1 = +8''.3$

T	ζ	δ	t	E	ΔT
$3^h\ 40^m\ 05^s.3$	76° 54′ 08″	+4° 38′ 34″	+43° 13′ 32″	$-3^m\ 22^s.4$	$-0^h\ 50^m\ 33^s.6$
3 44 38.6	77 04 09	+4 38 30	+44 22 42	−3 22.4	−0 50 30.2
				Mean . . .	−0 50 31.9

Observations for latitude, September 9th. Reflecting circle.

Circummeridian altitudes of the sun.

Index $\begin{cases} +32'\ 10'' & -31'\ 20'' \\ +32\ \ 20 & -31\ \ 20 \end{cases}$ $\begin{cases} +32'\ 10'' & -31'\ 20'' \\ +32\ \ 30 & -31\ \ 00 \end{cases}$ Correction $+31''.5$

(Applies to readings taken before $0^h\ 47^m$.)

Pocket chronometer	2☉	Pocket chronometer	2☉
$0^h\ 42^m\ 32^s$	33° 5′ {30″, 40}	$0^h\ 52^m\ 23^s$	33° 5′ {50″, 40}
43 19	33 6 {40, 30}	53 05	33 5 {50, 50}
44 35	33 7 {00, 00}	52 48	33 5 {40, 30}
	2☉̄		2☉̄
0 45 34	34 10 {20, 20}	0 55 17	34 8 {50, 30}
46 45	34 10 {50, 30}	55 59	34 8 {40, 30}
48 28	34 10 {00, 10}	56 38	34 8 {30, 20}

	$2\odot$		$2\odot$
$0^h\ 49^m\ 39^s$	$34^\circ\ 9'\ \begin{cases}50''\\40\end{cases}$	$0^h\ 57^m\ 25^s$	$33^\circ\ 4'\ \begin{cases}50''\\40\end{cases}$
50 24	$34\ \ 9\ \begin{cases}40\\30\end{cases}$	58 32	$33\ \ 4\ \begin{cases}20\\30\end{cases}$
51 24	$34\ \ 9\ \begin{cases}40\\30\end{cases}$	59 07	$33\ \ 4\ \begin{cases}00\\00\end{cases}$

$T = +28^\circ.0$, $B = 29^{in}.80$ at 62° Index $\begin{cases}+\ \ \ \ \ 00'' & -30'\ 40''\\ +33\ \ 20 & -30\ \ 30\end{cases}$ $\begin{cases}+32'\ 40'' & -30'\ 50''\\ +32\ \ 50 & -30\ \ 40\end{cases}$

$r = -3'\ 21''.8$ $\pi_1 = +8''.1$ Correction $+1'\ 09''$, applies after $0^h\ 47^m$

We have further—

$\delta = +5^\circ\ 04'\ 03''.3$	$\zeta_1 = 73^\circ\ 13'\ 36''$	$k^1 = [0.00024]$
$\delta_1 = +5\ \ 04\ \ 06.0$	$\delta T = +\ 3^s.2$	$A = 0.21119$
$\Delta\delta = -56''.87$	$\delta E = -20.6$	$\vartheta = -68^s.6$
		$y = -0''.5$

Mean time of apparent noon	$-0^h\ \ 2^m\ 59^s.3$
Chronometer error.	$+0\ \ 50\ \ 35.5$
Chronometer time of apparent noon	$0\ \ 47\ \ 36.2$
ϑ	$-0\ \ 1\ \ 08.6$
Chronometer time of sun's maximum altitude	$0\ \ 46\ \ 27.6$

T	h	mA	$h+mA$
$0^h\ 43^m\ 28^s.7$	$16^\circ\ 46'\ 09''$	$4''$	$16^\circ\ 46'\ 13''$
0 46 55.7	16 46 30	0	30
0 50 29.0	16 46 20	7	27
0 53 05.3	16 46 08	18	26
0 55 58.0	16 45 48	38	26
0 58 21.3	16 45 28	59	27

Mean, rejecting first value	16 46 27
$90 + \delta_1 + y$	95 04 06
φ	$78\ \ 17\ \ 39 \pm 1''.8$

Observations for Longitude of Port Foulke.

The material for the determination of longitude is very scanty, and the separate results cannot be made to harmonize as well as is desirable. It was Mr. Sonntag's intention to observe as many eclipses of Jupiter's first satellite as could be procured; unfortunately of this class of observations there are but four now available. The chronometric determination is very unreliable, although the indications of the three chronometers kept tolerably well together as far as Pröven, we find them, a month later, diverging to the extent of four minutes; it is evident, therefore, that they sustained considerable disturbances in their rate, undoubtedly produced by the concussions of the vessel with waves and ice. A third way by which I hoped to obtain at least a closely approximate result is partly astronomical, partly geodetic. The meridian of Van Rensselaer Harbor, Dr. Kane's winter quarters in 1853–'54–'55, is well determined astronomically by moon culminations, eclipses, and occultations, and by adding the geodetic difference of longitude between the two observatories, as measured on the track chart, a longitude for Port Foulke was obtained more in excess of its most probable value as that by the chronometers was in defect. We have, therefore, to infer that the distance between Smith Strait and Van Rensselaer Harbor was overrated by Kane.

I proceed to give the numerical results by each of the three methods.

The following four eclipses[1] of Jupiter's first satellite were noted by the pocket chronometer:—

1860. November 18 (19th A. M.). Disappearance $11^h\ 05^m\ 55^s$. A. Sonntag, observer.
Jupiter much waving, time uncertain to 20^s.

1861. January 30 (31st A. M.). Disappearance $12^h\ 27^m\ 46^s$. H. G. Radcliff, observer.
Note as above.

1861. February 6 (7th A. M.). Disappearance $2^h\ 21^m\ 42^s$. H. G. Radcliff, observer.
Planet unsteady, time uncertain to 5^s.

1861. February 8. Disappearance $8^h\ 51^m\ 23^s$. H. G. Radcliff, observer.
Very slight snow falling, time uncertain to 20^s.

The same magnifying power of telescope was used in the above observations.

We have no comparisons of chronometers on November 18, and as the pocket chronometer was allowed to run down between October 31 and November 29, its rate is determined from observations on October 17 and October 31, and its correction from observations on November 29.

Observations for time, October 17th, 1860.

Double altitudes of α Lyræ, with reflecting circle.

$$\text{Index}\begin{cases}+0'\ 40'' & +1'\ 40'' & +1'\ 00'' \\ +0\ \ 30 & +1\ \ 40 & +1\ \ 30\end{cases}\quad \text{Correction} + 1'\ 10'$$

Pocket chronometer	2∗	Pocket chronometer	2∗
$10^h\ 00^m\ 26^s$	84° 51′ {60″, 30}	$10^h\ 12^m\ 26^s$	83° 40′ {20, 20}
1 26	46 {00, 20}	13 19	34 {60, 50}
2 20	40 {10, 20}	14 18	28 {50, 50}
3 56	32 {20, 30}	15 30	22 {40, 30}
5 22	21 {20, 20}	16 43	16 {20, 10}
6 45	15 {20, 20}	17 45	8 {20, 10}
7 48	8 {20, 00}	18 56	0 {40, 50}
9 21	83 58 {10, 10}	20 13	82 54 {40, 30}
10 32	51 {70, 40}	21 02	49 {20, 00}
10 11 37	45 {30, 60}	22 08	42 {40, 60}

T = —2°, B = $29^{in}.390$ at 31°

$$\text{Index}\begin{cases}+1'\ 40'' & +1'\ 50'' & +1'\ 00'' \\ +1\ \ 40 & +1\ \ 40 & +1\ \ 10\end{cases}\quad \text{Corr'n} + 1'\ 30''$$

These observations will be combined two by two.

Refraction r for first observations $-1'\ 10''.3$, for last $-1'\ 12''.9$

Star's declination $\delta = +38°\ 39'\ 34''.9$, right ascension $18^h\ 32^m\ 13^s.5$

The hour angle t is found from $\cos t = \dfrac{\sin h - \sin \phi \sin \delta}{\cos \phi \cos \delta}$

[1] Three other observations were found to be occultations of the satellite, not eclipses; they are of no value for our purpose.

Sidereal time at mean noon $13^h\ 45^m\ 38^s.5$; the sidereal time is converted into mean time, and ΔT is the chronometer correction on mean local time.

T	h	t	ΔT
$10^h\ 00^m\ 56^s$	42° 23′ 58″	66° 43′ 37″	$-48^m\ 57^s$
10 03 08	42 17 39	67 15 39	—49 01
10 06 03.5	42 08 39	68 01 10	—48 55
10 08 34.5	42 01 04	68 39 26	—48 54
10 11 04.5	41 53 54	69 15 31	—49 00
10 12 52.5	41 48 17	69 43 38	—48 56
10 14 54	41 42 19	70 13 31	—48 58
10 17 14	41 35 35	70 47 14	—49 03
10 19 34.5	41 28 17	71 23 40	—48 58
10 21 35	41 22 27	71 52 47	—49 03
		Mean . .	—48 58.5 $\pm\ 0^s.7$

Observations for time, October 31, 1860.

Double altitudes of α Lyræ, with reflecting circle.

Index $\left\{\begin{matrix}+32'\ 00'' & -29'\ 20''\\ +32\ \ 20 & -28\ \ 50\end{matrix}\right\}$ $\left\{\begin{matrix}+1'\ 40'' & -1'\ 00''\\ +1\ \ 40 & -0\ \ 40\end{matrix}\right\}$ Mean correction + 1′ 23″.8

Pocket chronometer	2 *	Pocket chronometer	2 *
$9^h\ 08^m\ 26^s$	84° 34′ {60″, 40}	$9^h\ 21^m\ 21^s$	83° 17′ {40′, 40}
09 26	29 {10, 00}	22 23	12 {60, 20}
10 40	22 {20, 10}	23 23	05 {40, 40}
11 29	16 {60, 40}	24 20	00 {20, 20}
12 57	08 {60, 40}	25 52	82 50 {40, 60}
14 02	01 {30, 40}	27 22	41 {40, 20}
15 12	83 55 {40, 20}	28 48	32 {60, 40}
16 39	47 {20, 20}	29 43	27 {40, 20}
18 13	36 {20, 20}	30 47	21 {40, 20}
19 15	30 {80, 40}	31 30	15 {60, 40}

T = + 1.°5, B = 27^{in}.744 at 34° Index $\left\{\begin{matrix}+32'\ 30'' & -28'\ 20''\\ +32\ \ 40 & -28\ \ 20\end{matrix}\right\}$ $\left\{\begin{matrix}+32'\ 20'' & -28'\ 00''\\ +32\ \ 20 & -27\ \ 40\end{matrix}\right\}$

$r = -1'\ 10''.8$ and $r_1 = -1'\ 13''.7$ Mean correction + 2′ 11″.2

$\delta = +38°\ 39'\ 33''.3$

$\alpha =\ \ 18^h\ 32^m\ 13^s.2$

Sidereal time at mean noon $14^h\ 40^m\ 50^s.3$

T	h	t	ΔT
$9^h\ 08^m\ 56^s$	42° 15′ 42″	67° 25′ 26	$-49^m\ 13^s$
9 11 04.5	42 09 29	67 56 53	—49 16
9 13 29.5	42 02 18	68 33 00	—49 17
9 15 55.5	41 55 24	69 07 43	—49 24 rejected
9 18 44	41 46 32	69 52 19	—49 15
9 21 52	41 37 16	70 38 40	—49 18
9 23 51.5	41 31 11	71 08 51	—49 16
9 26 37	41 22 46	71 51 07	—49 14
9 29 15.5	41 14 45	72 30 59	—49 15
9 31 08.5	41 09 00	72 59 35	—49 13
		Mean	—49 15.2 $\pm\ 0^s.7$

Hence rate of pocket chronometer between October 17 and October 31, $\delta T = -1^s.2$

Observations for time, November 29th, 1860.

Double altitudes of α Lyræ, with reflecting circle.

Index $\left\{\begin{matrix} +32' \ 40'' & -30' \ 30'' \\ +32 \ \ 40 & -30 \ \ 50 \end{matrix}\right\}$ Correction + 1′ 0″

Pocket chronometer	2*	
6^h 23^m 50^s	84° 44′ $\left\{\begin{matrix}20'' \\ 20\end{matrix}\right.$	
25 48	32 $\left\{\begin{matrix}20 \\ 00\end{matrix}\right.$	T = + 21°
28 16	17 $\left\{\begin{matrix}20 \\ 00\end{matrix}\right.$	B = $30^{in}.076$ at 41°
30 55	02 $\left\{\begin{matrix}00 \\ 00\end{matrix}\right.$	
32 19	83 53 $\left\{\begin{matrix}40 \\ 40\end{matrix}\right.$	
35 17	36 $\left\{\begin{matrix}20 \\ 00\end{matrix}\right.$	
38 43	40 $\left\{\begin{matrix}60 \\ 40\end{matrix}\right.$	Index $\left\{\begin{matrix} +32' \ 20'' & -30' \ 40'' \\ +32 \ \ 00 & -30 \ \ 30 \end{matrix}\right\}$ Correction + 47″.5

$r = -1' \ 08''.4$ $\qquad r_4 = -1' \ 10''.1$

$\delta = +38° \ 39' \ 27''.6$

$\alpha = \ 18^h \ 32^m \ 12^s.8$

Sidereal time at mean noon 16^h 35^m $10^s.4$

T	h		ΔT
6^h 24^m 49^s	42° 18′ 25″	67° 11′ 12″	— 5^s
6 29 35.5	42 04 05	68 24 20	— 1
6 33 48	41 51 45	69 25 43	— 7
6 38 43	41 37 12	70 38 27	—12
			— $6^s.3 \pm 1^s.6$

Hence ΔT November 19th,	+ 6^s
Satellite I, disappearance,	11^h 05^m 55
Local mean time of eclipse,	23 06 01
Greenwich mean time,	27 57 12
Longitude Port Foulke,	4 51 11 west of Greenwich.

The correction of the pocket chronometer on local time, January 30th, is obtained by means of comparisons with the three mean time chronometers on that date, and the rates of these chronometers determined between November 29, 1860, and March 8, 1861.

Observations for time, March 8, 1861. S. J. McCormick, observer.

Altitudes of the sun. The times given are means of several observations, the corresponding mean altitudes are supposed corrected for index error.

Pocket chronometer	☉	
2^h 58^m 25^s	4° 10′ 18″	T = —15°
3 00 50.5	4 05 39	B = $29^{in}.5$ at 45°

$\pi = 8''$ $\qquad r = -12' \ 59'' \qquad r_1 = -13' \ 11''$

$\delta = -4° \ 38' \ 44''$ $\qquad$ hence :—

ζ	t	E	ΔT
85° 46′ 25″	+40° 50′ 00″	$+10^m$ $51^s.3$	-4^m $13^s.7$
85 51 16	+41 26 24	+10 51.3	—4 14.1
		Mean . . .	—4 13.9

Chronometer comparisons: November 29, 1860. Correction of pocket chronometer = — $6^s.3$

Pocket chronometer.	Mean time.	Chronometers.	Correction on mean time.
8^h 18^m $26^s.2$	8^h 18^m $19^s.9$	2007 : 1^h 8^m	-4^h 49^m $40^s.1$
19 44.9	19 38.6	1062 : 1 9	—4 49 21.4
20 43.2	20 36.9	740 : 1 10	—4 49 23.1

Chronometer comparisons: March 8, 1861. Correction of pocket chronometer — $4^m\ 13^s.9$

Pocket chronometer.	Mean time.	Chronometers.	Correction on mean time.
$3^h\ 38^m\ 37^s$	$3^h\ 34^m\ 23^s.1$	2007 : $8^h\ 22^m\ 20^s$	$-4^h\ 47^m\ 56^s.9$
3 39 11	3 34 57.1	1062 : 8 24 25	—4 49 27.9
3 39 35	3 35 21.1	740 : 8 25 45	—4 50 23.9

Rate, $\delta T = \dfrac{\Delta T - \Delta T_0}{99}$ for 2007: $+1^s.04$

1062: — 0.07

740: — 0.62

Pocket chronometer, — 2.50

Chronometer comparisons, January 31, 1861.

	ΔT Nov. 29.	δT	ΔT Jan'y 31.	Pocket chr. Jan'y 31.	Chron's Jan'y 31.	Mean time.	ΔT Pock. chr.
2007:	$-4^h\ 49^m\ 40^s.1$	$+1^s.04$	$-4^h\ 48^m\ 35^s$	$0^h\ 24^m\ 40^s$	2007 : $5^h\ 10^m\ 27^s$	$+21^m\ 52^s$	$-2^m\ 48^s$
1062:	—4 49 21.4	—0.07	—4 49 26	0 25 35	1062 : 5 12 27	+23 01	—2 34
740:	—4 49 23.1	—0.62	—4 50 02	0 26 32	740 : 5 13 47	+23 45	—2 47
P. chr.:	— 06.3	—2.50					—2 44
						Mean	—2 43

ΔT January 31, 1861	— $2^m\ 43^s$
Satellite I, disappearance	12 27 46
Local mean time of eclipse	12 25 03
Greenwich mean time	17 17 41
Longitude Port Foulke	4 52 38 west of Greenwich.

The local time for the two eclipses in February is obtained by means of chronometer comparisons on the 7th, and the rates of the chronometers and their corrections are previously determined.

Chronometer comparison February 7th, 1861.

Chronometers.	ΔT March 8.	ΔT Feb'y 7.	Pocket ch'r.	Mean time.	ΔT Pocket chr.
2007: $7^h\ 27^m\ 36^s$	$-4^h\ 47^m\ 56^s.9$	$-4^h\ 48^m\ 27^s$	$2^h\ 42^m\ 15^s$	$2^h\ 39^m\ 09^s$	$-3^m\ 06^s$
1062: 7 30 53	—4 49 27.9	—4 49 26	2 44 19.5	2 41 27	—2 53
740: 7 33 39	—4 50 23.9	—4 50 05	2 46 40	2 43 34	—3 06
Pocket chr.	—0 04 13.9				—3 01
				Mean	—3 01

Satellite I, disappearance	2 21 42
Local mean time of eclipse	14 18 41
Greenwich mean time	19 11 24
Longitude Port Foulke	4 52 43
Correction ΔT of pocket chronometer, February 8	—3 04
Satellite I, disappearance	8 51 23
Local mean time of eclipse	8 48 19
Greenwich mean time	13 39 52
Longitude Port Foulke	4 51 33

Recapitulation of Results for Longitude of Port Foulke from observed Eclipses of Jupiter's first Satellite.

1860.	November 18	$4^h\ 51^m\ 11^s$
1861.	January 30	4 52 38
1861.	February 6	4 52 43
1861.	February 8	4 51 33
	Mean . .	4 52 01 ± 16^s west of Greenwich.

The following time observations were reduced for the purpose of comparing the rates of the chronometers as found at Boston with rates determined at Port Foulke. The chronometer corrections are known from observations of September 9th, and of September 22d, 1860.

Observations for time, September 22d, 1860.

Double altitudes of α Lyræ, with reflecting circle.

$$\text{Index}\left\{\begin{array}{lll} +1'\ 10'' & +0'\ 40'' & +0'\ 40'' \\ +1\ \ 20 & +1\ \ 00 & +0\ \ 50 \end{array}\right\}\ \text{Correction} + 56''.7.$$

Pocket chronometer.	2*	Pocket chronometer.	2*
10h 43m 58s	90° 12′ {90″ / 50}	11h 08m 24s	87° 59′ {00″ / 20}
10 45 55	90 02 {20 / 20}	09 29	52 {10 / 00}
10 48 15	89 49 {20 / 20}	10 35	45 {40 / 60}
10 49 45	40 {40 / 60}	11 47	39 {60 / 50}
10 51 37	31 {10 / 00}	12 40	33 {40 / 20}
10 52 48	24 {40 / 60}	14 01	26 {30 / 40}
10 54 12	17 {20 / 20}	15 33	17 {60 / 40}
10 55 23	10 {50 / 40}	16 50	09 {40 / 40}
10 56 57	02 {50 / 50}	17 53	04 {10 / 40}
10 58 20	88 55 {20 / 10}	18 45	86 58 {40 / 80}

Index between the two sets.

$$\left\{\begin{array}{lll} +0'\ 40'' & +1'\ 10'' & +0'20'' \\ +0\ \ 50 & +1\ \ 20 & +0\ 30 \end{array}\right\}$$

Correction $+48''.3$

Index at the close of the observations.

$$\left\{\begin{array}{lll} +0'\ 50'' & +1'\ 20'' & +1'\ 20'' \\ +0\ \ 40 & +1\ \ 10 & 1\ \ 20 \end{array}\right\}$$

Correction $+66''.7$

$T = +20°.7$, $B = 29^{in}.72$ at 58°

$r = -61''.6$ and $r_1 = -65''.0$

$\delta = +38°\ 39'\ 35''.1$

$\alpha =\ \ 18^h\ 32^m\ 14^s.2$

Sidereal time at mean noon $12^h\ 07^m\ 04^s.7$

T	*h*	*t*	Δ*T*
10h 44m 56s.5	45° 03′ 17″	+52° 39′ 59″	—50m 45s
10 49 00	44 51 57	53 43 09	—50 36
10 52 12.5	44 43 23	54 30 33	—50 40
10 54 47.5	44 36 25	55 08 48	—50 42
10 57 38.5	44 28 54	55 49 48	—50 50
11 08 56.5	43 57 14	58 40 10	—50 48
11 11 11	43 50 52	59 14 02	—50 47
11 13 20.5	43 44 26	59 48 03	—50 41
11 16 11.5	43 36 16	60 30 55	—50 41
11 18 19	43 30 15	61 02 30	—50 43
		Mean . . .	—50 43.3 ± 0s.9

Chronometer comparisons: September 9, 1860. Correction of pocket chronometer —50m 35s1.

Pocket chronometer.	Mean time.	Chronometers.	Δ*T*
2h 27m 21s.5	1h 36m 46s.4	2007: 6h 29m	—4h 52m 13s.6
28 25.3	1 37 50.2	1062: 6 27	—4 49 09.8
29 05.5	1 38 30.4	740: 6 28	—4 49 29.6

September 10, 1860. Correction of pocket chronometer —50^m $31^s.9$

				Mean ΔT (9 & 10th)
0^h 41^m $22^s.0$	23^h 50^m $50^s.1$	2007 : 4^h 43^m	—4^h 52^m $09^s.9$	—4^h 52^m $11^s.8$
41 25.2	50 53.3	1062 : 4 40	—4 49 06.7	—4 49 08.3
42 05.3	51 33.4	740 : 4 41	—4 49 26.6	—4 49 28.2

September 22, 1860.

				δT Port Foulke	δT Boston.	Adopted δT
11^h 52^m $45^s.3$	11^h 02^m $02^s.0$	2007 : 15^h 54^m	—4^h 51^m $58^s.0$	$+1^s.06$	$+0^s.4$	$+0^s.6$
53 31.2	11 02 47.9	1062 : 15 52	—4 49 12.1	—0.29	+0.2	0.0
54 08.7	11 03 25.4	740 : 15 53	—4 49 34.6	—0.49	0.0	—0.2

The adopted rate is found by giving the weight $\frac{1}{2}$ to the Port Foulke rate to make some allowance for the effect of the greater cold at this place. There are no means of obtaining sea rates for the chronometers.

We have accordingly the following chronometric results:—

ΔT July 7th on Greenwich time.	ΔT September 9th on Greenwich time.	ΔT September 9 & 10 On Port Foulke time.	Longitude of Port Foulke.
2007: $+1^m$ $35^s.3$	$+2^m$ 14^s	—4^h 52^m 12^s	4^h 54^m 26^s
1062: +0 57.0	+0 57	—4 49 08	4 50 05
740: +1 14.7	+1 02	—4 49 28	4 50 30
		Mean	4 51 40 ± 56^s

A result to which we can attach but little value.

The determination of the longitude of Port Foulke by means of the known meridian of Van Rensselaer Harbor, and the geodetic difference of longitude with Port Foulke, involves as an intermediate step the position of Cairn Point if we wish to deduce the most reliable result. Cairn Point is the northern terminal cape of Smith Strait, as Cape Alexander is that of the southern, both located on the Greenland shore. At Cairn Point numerous measures were taken, important for the geography of the strait, besides it served as a point of departure for the northern journeys. Before, however, giving the astronomical observations at this point, the remaining time observations taken at Port Foulke, and required for the determination of the longitude of Cairn Point and other stations, will first be given.

Observations for time, Port Foulke, May 29th, 1861.

Altitudes of the sun. S. J. McCormick, observer.

Chronometer 2007	⊙	
7^h 10^m 24^s	30° 45′ 40″	T = + 32°
10 55	43 20	B = $29^{in}.72$ at 56°
11 30	42 30	Correction for index, dip, refraction and parallax = — 5′ 04″

N. B. Refraction very great when these sights were taken.

Semidiameter 15′ 48″

T	ζ	δ	t	E	ΔT
7^h 10^m $56^s.3$	59° 05′ 26″	+21° 42′ 40″	36° 32′ 10″	—2^m $52^s.6$	4^h 47^m $40^s.6$

Altitudes of the sun, June 7th, 1861. S. J. McCormick, observer.

Chronometer 2007	⊙	
7^h 58^m 12^s	30° 09′ 10″	T = + 32°
58 43	08 10	B = $29^{in}.72$ at 54°
59 07	07 10	Corrections as above. Semidiameter 15′ 47″

Ordinary refraction

T	ζ	δ	t	E	ΔT
7^h 58^m $40^s.7$	59° 41′ 07″	+22° 49′ 09″	48° 03′ 26″	—1^m $25^s.3$	4^h 47^m $52^s.3$

Altitudes of the sun, June 8th, 1861. S. J. McCormick, observer.

Chronometer 2007	$\underline{\odot}$	
7h 46m 23s	30° 42′ 50″	T = + 34°
46 49	41 50	B = 29in.69 at 49°
47 16	41 00	Corrections as above. Semidiameter 15′ 47″

Ordinary refraction.

T	ζ	δ	*t*	*E*	Δ*T*
7h 46m 49s.3	59° 07′ 24″	+22° 54′ 30″	45° 02′ 59″	—1m 14s.0	—4h 47m 51s.3

Altitudes of the sun, July 7th, 1861. S. J. McCormick, observer

Chronometer 2007	$\underline{\odot}$	
7h 59m 05s	30° 4′ 40″	T = + 48°
59 41	2 30	B = 29in.64 at 58°
8 00 34	0 30	Correction for index, dip, refraction, and parallax —5′ 07″.0
		Semidiameter 15′ 46″.2
	$\overline{\odot}$	
8h 01m 17s	29° 58′ 40″	
01 55	57 20	
02 45	56 00	

T	ζ	δ		*E*	Δ*T*
7h 59m 46s.7	59° 46′ 47″	+22° 32′ 46″	46° 58′ 4″	+4m 36s.4	—4h 47m 18s.0
8 01 59.0	59 52 01	+22 32 45	47 30 50	+4 36.5	—4 47 19.2
				Mean . . .	—4 47 18.6

Altitudes of the sun, July 13th, 1861. S. J. McCormick, observer.

Chronometer 2007	$\underline{\odot}$	
7h 58m 50s	29° 20′ 50″	T = + 43°
59 30	19 00	B = 30in.09 at 57°
8 00 09	17 00	Correction for index, dip, refraction, and parallax —5′ 09″

T	ζ	δ	*t*	*E*	Δ*T*
7h 59m 29s.7	60° 30′ 26″	+21° 46′ 03″	46° 42′ 56″	+5m 26s.5	—4h 47m 11s.5

Omitting the result of May 29th, on account of unusual refraction, we have the following chronometer corrections and rate:—

Port Foulke.	Chronometer 2007 Δ	δ*T*
1861. March 8	—4h 47m 56s.9	
1861. June 7	—4 47 52.3 }	+0s.6
1861. June 8	—4 47 51.3 }	
1861. July 7	—4 47 18.6 }	+1.12
1861. July 13	—4 47 11.5 }	

The correction and rate of the pocket chronometer we obtain from the following chronometer comparisons. The pocket chronometer had run down March 18 and was set approximately to mean local time March 22.

Comparisons for the observations at Cairn Point.

Chronometer comparisons April 8th, 1861, at Port Foulke.

Pocket chronometer.	Chronometers.	Δ*T* Port Foulke.	Mean time Port Foulke.	Δ*T* Pocket chron'r on Port Foulke time.
1h 49m 59s.2	740 : 6h 33m	—4h 51m 20s.6	1h 41m 39s.4	—8m 19s.8
1 51 36.5	1062 : 6 33	—4 49 43.1	1 43 16.9	—8 19.6
1 53 24.2	2007 : 6 33	—4 47 55.1	1 45 04.9	—8 19.3
			Mean . . .	—8 19.6

6h 34m 12s of 2007 = 6h 36m of 1062

6 36 of 2007 = 6 39 25s.5 of 740

Chronometer comparisons, April 16th, 1861, at Port Foulke.

Pocket chronometer.	Chronometers.	ΔT Port Foulke.	Mean time Port Foulke.	ΔT Pocket chron'r on Port Foulke time.
3^h 56^m $58^s.8$	2007: 8^h 36^m	-4^h 47^m $54^s.6$	3^h 48^m $05^s.4$	-8^m $53^s.4$
3 59 05.5	1062: 8 40	—4 49 47.6	3 50 12.4	—8 53.1
4 01 14.2	740: 8 44	—4 51 39.1	3 52 20.9	—8 53.3
			Mean . . .	—8 53 3

8^h 43^m of 2007 = 8^h 44^m 53^s of 1062
8 45 of 2007 = 8 48 44.5 of 740

δT of pocket chronometer = — $4^s.2$

Cairn Point, Smith Strait.

Observations for latitude of Cairn Point, April 12th, 1861.

Meridian altitude of the sun. S. J. McCormick, observer.

	2☉	
	40° 13′ 0″	T = — 5°
Index correction +	2 0	B = $29^{in}.90$ at 66°
Altitude . . .	20 07 30	Approximate longitude 4^h $51\frac{1}{3}^m$ west of Greenwich.
Refraction—par. —	2 50	
Semidiameter . +	15 59	
Max. alt. . . .	20 20 39	
δ at appa't noon	8 51 23	
φ	78 30 42	Latitude of Cairn Point.

Observations for latitude of Cairn Point, April 15th, 1861.

Meridian altitude of the sun. S. J. McCormick, observer.

	2☉	
	42° 22′ 0″	T = — 10°
Index correction +	2 0	B = $30^{in}.21$ at 56°
Altitude . . .	21 12 00	
Refraction—par. —	2 44	
Semidiameter . +	15 59	
Max. alt. . . .	21 25 15	
δ at appa't noon	9 56 11	
φ	78 30 56	Latitude of Cairn Point.

The difference between the maximum altitude and the meridian altitude, owing to the change in the sun's declination, amounts in the present case to 0″.5, and may therefore be neglected.

Taking the mean value of φ we find the latitude of Cairn Point, 78° 30′ 49″

Observations for time and longitude of Cairn Point, April 15, 1861.

Double altitudes of the sun. S. J. McCormick, observer.

Pocket chronometer.	2☉	
3^h 29^m 42^s	33° 50′	T = — 10°
30 36	46	B = $30^{in}.19$ at 55°
31 09	42	Index correction + 2′ 0″
r = 3′ 38″	π = 8″	Semidiameter = 15′ 58″

T	ζ	δ	t	E	ΔT
3^h 30^m 29^s	72° 53′ 32″	+ 9° 59′ 03″	50° 41′ 04″	-6^s	-7^m 51^s
		Pocket chronometer, ΔT on Port Foulke time,			—8 49.1
		Longitude of Cairn Point, east of Port Foulke,			0 58.

Adopting the value $4^h\ 52^m\ 0^s$ for the longitude of Port Foulke, we have the longitude of Cairn Point $4^h\ 51^m\ 02^s$; the observer used a smaller difference of longitude from which I infer that the chronometer correction of the 8th was preferred with an average rate of $-2^s.5$, in this case we have ΔT on Port Foulke time $-8^m\ 37^s$, hence the latitude of Cairn Point $4^h\ 51^m\ 14^s$, which is adopted (see also determination from bearings further on).

Returning to the longitude of Port Foulke, by means of the known meridian of Van Rensselaer Harbor determined by Kane, we have the astronomical longitude of the latter place, as computed by me from moon culminations, occultations, and an eclipse[1] $4^h\ 43^m\ 31^s$, also Cairn Point west of Van Rensselaer Harbor by Kane's large track chart $11^m\ 32^s$, and by the above, Port Foulke west of Cairn Point 46^s; hence longitude of Port Foulke $4^h\ 55^m\ 49^s$, a result certainly too large, which can only be accounted for by an over estimation of the distance between Kane's winter quarters and Cairn Point; this apparent excess amounts to $13\frac{1}{2}$ miles in linear measure; part of it, however, we must attribute also to the meridian adopted for each of the observatories.[2]

For the longitude of Port Foulke the value $4^h\ 52^m\ 00^s$ or 73° 00′ west has been adopted. The probable uncertainty of this value is one statute mile.

The following positions were determined by Dr. Hayes (or party) on his trip across the strait and up the west coast of Kennedy Channel in April and May. He started from Cairn Point April 20, 1861.

Camp Separation, Smith Sound.

Observations for latitude of camp, April 25th, 1861.

Meridian altitude of the sun. S. J. McCormick, observer.

			$2\odot$	
	48°	27′	00″	T = —12°
Index correction . +		1	00	B = $29^{in}.9$ at 51° as recorded at Port Foulke, it answers as a rough approximation.
Altitude . . .	24	14	00	
Refraction—par. . —		2	20	
Semidiameter . . +		15	55	Approximate longitude $4^h\ 48\frac{1}{2}^m$ west of Greenwich.
Maximum altitude	24	27	35	
δ at apparent noon	13	20	30	
ϕ	78	52	55	

---

[1] Smithsonian Contributions, 1860: Kane's Astronomical Observations in the Arctic Seas, p. 33.

[2] I have also attempted to work out a result for longitude from three observed double altitudes of the moon's lower limb February 17, 1861; the observations, however, were found too crude, the sextant reading was given to the nearest minute only.

Camp Frazer, SMITH SOUND.

Observations for latitude of camp, May 14th, 1861.
Meridian altitude of the sun. Dr. I. I. Hayes, observer.

		2⊙		
Pocket sextant[1] .		58°	16′	T = + 28°
Index correction .	—	1	28	B = 30^in^.3 at 67° approximately.
		56	48	Approximate longitude $4^h\ 42\frac{1}{2}^m$
Altitude . . .		28	24.0	
Refraction—par. .	—		1.8	
Semidiameter . .	+		15.9	
Maximum altitude		28	38.1	
δ at apparent noon		18	44.4	
φ		80	06.3	

Farthest Camp, KENNEDY CHANNEL.

Observations for latitude of camp, May 17th, 1861.
Meridian altitude of the sun. Dr. I. I. Hayes, observer

		2⊙		
Pocket sextant . .		56°	52′	T = + 22°
Index correction . .	—	1	31	B = $30^{in}.0$ at 53° approximately.
		55	21	Approximate longitude $4^h\ 35\frac{1}{2}^m$
Altitude		27	40.5	
Refraction—par. .	—		1.8	
Semidiameter . .	+		15.8	
Maximum altitude .		27	54.5	
δ at apparent noon .		19	26.0	
φ		81	31.5	

Camp Leidy, SMITH SOUND.

Observations for latitude of camp, May 20th, 1861.
Meridian altitude of the sun. Dr. I. I. Hayes, observer.

		2⊙		
Pocket sextant . .		61°	14′	T = + 22° (about)
Index correction .	—	1	30	B = $29^{in}.7$ at 52° approximately.
		59	44	Approximate longitude $4^h\ 44^m$
Altitude		29	52.0	
Refraction—par. .	—		1.7	
Semidiameter . .	+		15.8	
Maximum altitude		30	06.1	
δ at apparent noon		20	04.6	
φ		79	58.5	

[1] This pocket sextant (Gilbert's No. 3) left in the same condition as on the return from the northern journey, was handed to me by Dr. Hayes for examination. I found the adjustment of the perpendicularity of the two mirrors quite perfect; the index error by means of a sharp vertical line, was 1° 30′ on the arc, and by means of four measures of twice the sun's diameter 1° 32′ on the arc, the correction was therefore —1° 31′.6. February 5, 1862.—CHAS. A. S.

Deep Snow Camp, SMITH SOUND.

Observations for latitude of camp, May 21st, 1861.

Meridian altitude of the sun, Dr. I. I. Hayes, observer.

		2☉	
Pocket sextant . .		61° 48′	$T = + 22°$ (about).
Index correction .	—	1 32	$B = 30^{in}.0$ at 60° approximately.
		60 16	Approximate longitude $4^h\ 51^m$
Altitude		30 08.0	
Refraction—par. .	—	1.7	
Semidiameter . .	+	15.8	
Maximum altitude .		30 22.1	
δ at apparent noon		20 16.9	
φ		79 54.8	

Camp Hawks, SMITH SOUND.

Observations for latitude of camp, May 22d, 1861

Meridian altitude of the sun. Dr. I. I. Hayes, observe.

		2☉	
Pocket sextant . .		62° 34′	$T = + 20°$ (about).
Index correction .	—	1 32	$B = 30^{in}.1$ at 58 approximately.
		61 02	Approximate longitude $4^h\ 53^m$
Altitude		30 31.0	
Refraction—par .	—	1.7	
Semidiameter . .	+	15.8	
Maximum altitude .		30 45.1	
δ at apparent noon .		20 28.8	
φ		79 43.7	

Small berg Camp, SMITH SOUND.

Observations for latitude of camp, May 23d, 1861.

The meridian altitude of the sun is recorded 2☉ 62° 58′ with a ? attached. As the resulting latitude is the same as that of the preceding camp, and the position of the camp on the track chart disagrees with it, I shall make no use of this observation.

Scouse Camp, SMITH SOUND.

Observations for latitude of camp, May 23d, 1861.

Meridian altitude of the sun, lower culmination.[1] Dr. I. I. Hayes, observer.

		2☉	
Pocket sextant . .		21° 40′	$T = + 18°$ (about).
Index correction .	—	1 31	$B = 29^{in}.9$ at 65° approximately.
		20 09	Approximate longitude $4^h\ 52\frac{3}{4}^m$
Altitude		10 04.5	
Refraction—par. .	—	5.5	
Semidiameter . .	+	15.8	
Minimum altitude .		10 14.8	
δ at apparent midnight		20 45.8	
φ		79 29.0	

[1] For upper culmination, $\varphi = 90 + \delta - h$
For lower culmination, $\varphi = 90 - \delta + h$

Determination of Longitudes for the Northern Journey.—These principally depend upon observed bearings of known headlands to the south, and some sextant angles. A few chronometric determinations depend upon the following chronometer corrections as found at Port Foulke, April 16th, and May 30th, and June 1st, 1861. For rate we are obliged to use the previously determined value, viz: $\delta T = -2^s.5$ since the pocket chronometer had evidently stopped more than an hour on or before May 13, occasioned by a neglect to wind at the proper time

April 16, 1861 ΔT at Port Foulke $= - 8^m\ 53^s.3$

Chronometer comparisons, May 30th, 1861, at Port Foulke, two days after Dr. Hayes' return.

Pocket chro'r May 30.	Chronom'r 2007.	ΔT of 2007 June 7 and 8.	δT of 2007.	ΔT of 2007 May 30.	Mean time of comparison.	ΔT of pocket chr. May 30.
$9^h\ 00^m\ 51^s$	$3^h\ 1^m$	$-4^h\ 47^m\ 51^s.8$	$+0^s.06$	$-4^h\ 47^m\ 52^s.1$	$10^h\ 13^m\ 07^s.9$	$+1^h\ 12^m\ 16^s.9$

June 1.		June 1.	Mean time of comparison.	ΔT of pocket chr. June 1.	δT of pocket chronometer.
$7^h\ 34^m\ 56^s.2$	$1^h\ 35^m$	$-4^h\ 47^m\ 52^s.2$	$8^h\ 47^m\ 07^s.8$	$+1^h\ 12^m\ 11^s.6$	$-2^s.6$

Foggy Camp, Smith Sound.

Observations for longitude, May 13. I. I. Hayes, observer.

ocket chronometer.	$2\odot$ by pocket sextant.	
$3^h\ 53^m\ 52^s$	40° 37′	Assumed latitude 79° 55′.5, longitude $4^h\ 47^m$
	$2\underline{\odot}$	T = + 20° (about)
3 58 48	42 28	B = $30^{in}.0$ at 51° approximately.
3 59 52	42 22	Index correction — 1° 28′.0
4 00 26	42 17	Refraction—par. 2′7
3 59 42	42 22.3	$h = 19°\ 58'.1$ $\delta = 18°\ 32'\ 18''$
		$t = 80\ \ 7'\ 10''$ $E = -3^m\ 53^s.4$

Mean time of observation,	$5^h\ 16^m\ 35^s$	
Chronometer time,	3 56 47	
ΔT	+ 1 19 48	
ΔT Port Foulke,	+ 1 12 58	Deduced from correction of May 30th.
Difference of longitude,	$6^m\ 50^s$	Foggy camp east of Port Foulke.
Longitude of Foggy camp,	$4^h\ 45^m\ 10^s$	(See determination from bearings further on.)

Camp Hawks, Smith Sound.

Observations for longitude, May 22. I. I. Hayes, observer.

Pocket chronometer.	$2\odot$ by pocket sextant.	
$7^h\ 09^m\ 55^s$	29° 24′	T = + 13° (about).
11 17	19	B = $30^{in}.1$ at 58° approximately.
12 05	14	Index correction —1° 32′.0
7 11 06	29 19	Approximate longitude, $4^h\ 53^m$
	$2\underline{\odot}$	
$7^h\ 13^m\ 05^s$	30° 24′	Refraction—par. —4′.0
14 55	18	
7 14 00	30 21	$h = 14°\ 05.'0$ $\delta = 20°\ 32'\ 50''$
		$t = 127\ \ 39'\ 47''$ $E = -3^m\ 34^s.1$

Mean time of observation,	$8^h\ 27^m\ 05^s$	
Chronometer time,	7 12 33	
ΔT	+ 1 14 32	
ΔT Port Foulke,	+ 1 12 36	Deduced from correction of May 30th.
Difference of longitude,	+ 1 56	Camp Hawks east of Port Foulke.
Longitude of Camp Hawks,	4 50 04	(See determination from bearings further on.)

Magnetic Bearings for Position of Camps and Headlands.

The numerous magnetic bearings, taken at important positions on land and upon the ice, were made use of for the construction of a chart,[1] scale 1 : 1200 000. The chart depends upon the astronomical results just deduced; by means of these and a critical use of the bearings and sextant angles, the western shore line and that south of Smith Strait were finally laid down. All detail is taken from Dr. Hayes' original track chart (scale 1 : 600 000), to which I have closely adhered, as far as the above material would permit.

The longitude of Cairn Point, from observed bearings, is as follows:—

From bearings at Cairn Point,	72°	50′	Adopted longitude 72° 59′
" " " Littleton Island;	73	10	
" " " McGary Island,	73	05	
By chronometer,	72	48	

The longitude of Foggy Camp, from observed bearings, is as follows: 71° 33′, from chronometric determination 71° 17′ giving the former result the weight 2, the weighted mean becomes 71° 28′, which has been adopted.

The longitude of Camp Hawks from bearings is 73° 24′, from chronometric determination 72° 31′ giving the former result the weight 2, the weighted mean becomes 73° 06′ or $4^h\ 52^m\ 24^s$, which has been adopted.

Dr. Hayes reached Cairn Point May 27th, 3½ A. M., and Port Foulke May 28th, 10 A. M.

Survey of Smith Strait.

On the 27th of October, 1860, Mr. Sonntag measured a base line on the ice from the outer point of the third or Starr Island, near Port Foulke, bearing magnetically S. 4° 20′ W. The length of this base, from two measures with a 91 foot line, was 9097 feet, or 2772.9 metres. The position of Cape Isabella and of Cape Patterson, on the coast opposite, were determined from angles measured at the extremities of this base.

Readings of theodolite:—

						Mean.
At Third Island:	Base end,	193°	51′	52′	52½′	193° 51′.9
			50	53	53	
	Cape Patterson,	312	43	45		312 44.8
			44	47		
	Cape Isabella,	348	13	13		348 14.0
			15	15		
At opposite end of base:	Third Island,	116	30	29	30	116 29.5
			30	28	30	
	Cape Isabella,	92	03	04	04	92 03.8
			04	04	04	
	Cape Patterson,	57	12	12		57 12.2
			13	12		

Solving the triangles:	Isabella,	1°	11′.8	and	Cape Patterson,	1°	49′.8
	Third Island,	154	22.5		Third Island,	118	52.9
	Base end,	24	25.7		Base end,	59	17.3

[1] See large chart accompanying this paper.

We find the distances:—

Third Island to Cape Isabella,	34.12 st. miles, or	29.65 naut. miles.	
" " Cape Patterson,	46.39 "	40.30 "	

The latitude and longitude of these capes we deduce from the known position of Third Island,[1] viz: latitude 78° 17′ 45″, longitude 73° 06′ 00″, and the known variation, viz: $9\frac{3}{4}$° west. Forming the spherical triangle pole, Third Island, Isabella (or Patterson) of which is given the colatitude of Third Island, the distance to Isabella (or Patterson) and the included spherical angle, we find—

Cape Isabella,	latitude 78° 22′.4	longitude 75° 30′.8
Cape Patterson,	" 78 46.1	" 75 30.5

We have also a direct determination of the latitude of Cape Isabella by Dr. Hayes, viz:—

Meridian altitude of sun, lower culmination, July 28th, 1861.

	2☉			
Observed double alt.,	14°	1′	30″	T = + 49°
Index correction,		0	00	B = 29in.9 at 58°
Observed altitude,	7	0	45	
Refraction—par.,	—	7	17	
Semidiameter,	+	15	48	
Minimum altitude,	7	09	16	
δ at apparent midnight,	18	47	09	
φ	78	22	07	which agrees closely with the above geodetic latitude.

McGary Island, OPPOSITE LITTLETON ISLAND, SMITH STRAIT.

Observations for latitude of McGary Island, at southwest end of Island, July 6, 1861.

Meridian altitude of the sun. I. I. Hayes, observer.

	2☉			
	68°	04′	00″	T = + 42°
Index correction,	+	1	00	B = 29in.4 at 54°
Altitude,	34	02	30	Assumed longitude $4^h\ 53\frac{1}{2}^m$
Refraction—par.,	—	1	20	
Semidiameter,	+	15	46	
Maximum altitude,	34	16	56	
δ at apparent noon,	22	39	59	
φ	78	23	03	Latitude of McGary Island.

On the 12th of June 1855, Kane[2] determined the latitude of Littleton Island and found 78° 22′ 01″. I adopt the mean of these determinations, or 78° 22′ 32″ for the channel between the two islands.

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[1] See accompanying chart of Port Foulke and vicinity, scale 1:170 000.

[2] Smithsonian Contributions, 1860: Kane's Astronomical Observations in the Arctic Seas, p 44.

Littleton Island, SMITH STRAIT.

Observations for time and longitude, July 21 (22d A. M.), 1861.

Double altitudes of the sun. H. G. Radcliff, observer.

Chronometer 2007[1]	$2\overline{\odot}$	
3ʰ 34ᵐ 03ˢ	62° 42′ 40″	T = + 34°
34 49	43 10	B = 29ⁱⁿ.6 at 72°
36 17	44 10	Index correction + 1′ 04″
		Semidiameter 15′ 47″
	$2\underline{\odot}$	$r = 1' 37''$ $r_1 = 1' 39''$
3 39 00	61 50 00	$\pi = 8''$
39 57	51 40	
41 14	54 10	

T	ζ	δ	t	E	ΔT
3ʰ 35ᵐ 03ˢ.0	58° 55′ 04″	20° 13′ 24″	—19° 59′ 39″	+6ᵐ 07ˢ.6	—4ʰ 48ᵐ 54ˢ.1
3 40 03.7	58 49 14	20 13 22	—18 39 26	+6 07.6	—4 48 33.8
				Mean	—4 48 44

Observations for time and longitude, July 26th, 1861.

Chronometer 2007.[2]	Corrected alt. $\odot$	
7ʰ 51ᵐ 10ˢ	27° 33′ 50″	T = + 44°
53 19	27 28 55	B = 29ⁱⁿ.88 at 55°
58 12	27 18 01	
8 02 21	27 08 31	
04 53	27 02 43	
06 49	26 57 42	

T	ζ	δ	t	E	ΔT
7ʰ 59ᵐ 27ˢ.3	62° 45′ 03″	19° 20′ 06″	45° 16′ 20″	+6ᵐ 11ˢ.5	—4ʰ 49ᵐ 03ˢ.2

Longitude of Littleton Island.

	ΔT Litt. Island.	ΔT Port Foulke.	Litt. Is. west.
1861, July 21	—4ʰ 48ᵐ 44ˢ	—4ʰ 47ᵐ 02ˢ	1ᵐ 42ˢ
1861, July 26	—4 49 03	—4 46 57	2 06
		Mean	1 54

If we reject the second set of observations on the 21st, the two results for difference of longitude become 1ᵐ 52ˢ and 2ᵐ 06ˢ, the mean 1ᵐ 59ˢ is adopted. The longitude of Littleton Island becomes therefore 4ʰ 53ᵐ 59ˢ, which agrees well with the geodetic determination, for which see chart of Port Foulke and vicinity.

This chart puts Cape Alexander in latitude 78° 10′.5. Dr. Kane found, June 17, 1855, the latitude 78° 09′.3, a result which agrees well enough with the chart.

[1] The chronometer minutes have been changed from 35ᵐ to 34ᵐ.

[2] The above times are the observed times — 3ᵐ 07ˢ.3, by which correction the observer intended them to represent Greenwich time.

Gale Point, NEAR CAPE ISABELLA, SMITH STRAIT.

Observations for latitude at anchorage off Gale Point, July 27, 1861.[1]

Meridian altitude of the sun. S. J. McCormick, observer.

Gale Point bears S. W. (true), and Cape Isabella N. E. by N. (true).

Observed altitude $\odot$	30°	45′	40″	Approximate longitude $5^h\ 5^m$
Dip and index correction, —		3	19	
	30	42	21	
Refr'n—par.	—	1	30	
Semidiameter,	+	15	48	
True altitude,	30	56	39	
δ at apparent noon,	19	08	08	
ϕ	78	11	29	

Observations for longitude, sights taken from a grounded iceberg off Gale Point.

Double altitudes of the sun. S. J. McCormick, observer. July 28 (29th A. M.)

Pocket chronometer	$2\odot$	
$2^h\ 39^m\ 58^s$	55° 29′ 30″	T = + 50° } about
40 22	31 50	B = $29^{in}.8$ at 54° } about
40 56	34 40	Approximate longitude, $5^h\ 6^m$
	$2\odot$	Index correction, 0′ 0″
2 41 25	55 36 00	Refr.—par. —1′ 42″
42 03	38 20	Semidiameter, +15′ 48″
42 27	39 50	h = 28° 01′ 37″ δ = 18° 41′ 35″
		t = — 36° 19′ 00″ E = + $6^m\ 10^s$

Chronometer time of observation,	2^h	41^m	11^s	
Reduction[2] to refer pocket ch'r to ch'r 2007,	—	1	33	
(2007) Chronometer time of observation,	2	39	38	
Mean time of observation,	21	40	54	
ΔT off Gale Point,	—4	58	44	
ΔT Port Foulke,	—4	46	55	(see preceding table of ΔT and δT of 2007)
Iceberg off Gale Point, W. of Port Foulke,		11	49	
Longitude of position,	5	03	49	west of Greenwich.

The following observations on Upper Baffin Bay conclude the series of geographical positions:—

Netlik, SOUTHERN ENTRANCE TO WHALE SOUND.

Observations for latitude at north point of harbor, close to Esquimaux huts, August 5, 1861.

Meridian altitude of the sun. S. J. McCormick, observer.

$2\odot$	59°	01′	20″	
Index correction,		0	00	T = + 47° } about
Altitude observed,	29	30	40	B = $29^{in}.9$ at 50° } about
Refr'n—par.,	—	1	35	Approximate longitude, $4^h\ 46^m$
Semidiameter,	+	15	49	
h	29	44	54	
δ at apparent noon,	16	52	40	
ϕ	77	07	46	

[1] There is some doubt about the date; the record gives 28th, but the statement that the position is about 10 miles south of Cape Isabella and the plotted position on the track chart, accord well with the corrected date, and with the above resulting latitude.

[2] Chronometer comparison: 2007, $6^h\ 34^m$, Pocket chronometer $6^h\ 35^m\ 33^s.2$.

Observations for longitude, August 4 (5th A. M.).

Double altitudes of the sun. S. J. McCormick, observer.

Pocket chronometer.	2☉	
$2^h\ 20^m\ 17^s$	53° 33′ 30″	T = + 38°, B $29^{in}.9$ at 50° } about
20 49	34 40	
21 07	36 10	Index correction 0′ 0″
Mean, 2 20 44	53 34 47	Refr'n—par. — 1′ 50″
Reduction[1] to 2007, — 1 50		Semidiameter + 15′ 49″
T 2 18 54		$h =$ 27° 01′ 22″ δ = 16° 54′ 21″
		t = —36 42 40 $E = + 5^m\ 41^s$

Mean time of observation,	$21^h\ 38^m\ 50^s$	
Chronometer time,	26 18 54	
ΔT Netlik,	—4 40 04	
ΔT Port Foulke,	—4 46 36	(see preceding table of ΔT and δT of 2007.)
Netlik east of Port Foulke,	6 32	
Longitude of Netlik,	4 45 28	west of Greenwich.

Upernavik, North Greenland.

Observation for latitude, August 16, 1861.

Meridian altitude of the sun. S. J. McCormick, observer.

2☉	61° 13′ 50″	
Index correction,	0 00	T = + 51°
Altitude observed,	30 36 55	B = $29^{in}.9$ at 51°
Refr.—par.,	— 1 30	Assumed longitude $3^h\ 44^m$
Semidiameter,	+ 15 51	
h	30 51 16	
δ at apparent noon,	13 38 03	
ϕ	72 46 47	

Dr. Kane, in 1853, found this latitude 72° 46′ 12″ (Sonntag observer; see p. 37 of Kane's Astronomical Observations); according to Captain Inglefield the latitude is 72° 46′ 51″; the mean of the three determinations is 72° 46′ 37″.

Observations for time at Upernavik, August 15, 1861.

Double altitude of the sun. S. J. McCormick, observer.

Chronometer 2007	2☉	
$6^h\ 35^m\ 24^s$	52° 00′ 30″	T = + 50°
35 59	51 57 20	B = $29^{in}.9$ at 54°
36 24	51 54 40	Index correction, 0′ 00″
36 53	51 50 50	Refr'n—par., — 1 40
37 20	51 48 20	Semidiameter, +15 50
37 43	51 45 30	
38 07.5	51 42 10	h = 26° 09′ 01″ δ = + 13° 54′ 52″
38 30.5	51 40 50	t = 42 45 10 $E = + 4^m\ 10^s$
Mean, 6 37 02.8	51 50 01	

[1] Chronometer comparison: 2007, $7^h\ 42^m$, Pocket chronometer, $7^h\ 43^m\ 50^s$.

Mean time of observation	2^h	55^m	11^s
Chronometer time[1]	6	34	41
ΔT	—3	39	30
ΔT Port Foulke	—4	46	35
Difference of long. Port Foulke and Upernavik	1	07	05
Longitude of Upernavik according to Inglefield	3	44	11
Longitude of Port Foulke	4	51	16 west of Greenwich.

(If the times had been noted by 2007, this longitude would be smaller by $2^m\ 22^s$). These time observations at Upernavik I have introduced to show that their tendency is still more to lessen the adopted longitude of Port Foulke, or else to increase the adopted longitude of Upernavik; placing but little confidence in the result, I make no further use of it.

RECAPITULATION OF PRECEDING RESULTS FOR GEOGRAPHICAL POSITIONS.

Locality.	Latitude.	Longitude west of Greenwich. In arc.	Longitude west of Greenwich. In time.
Port Foulke, Observatory, Smith Strait	78° 17′ 39″	73° 00′ 00″	$4^h\ 52^m\ 00^s$
Littleton Island, Smith Strait	78 22.5	73 29 45	4 53 59
McGary Island, " "	78 23.1	- - - - - - - -	- - - - - - -
Cairn Point, " "	78 30 49	72 59	4 51 56
Cape Isabella " "	78 22 15	75 30.8	5 02 03
Off Gale Point, " "	78 11.5	75 57.2	5 03 49
Cape Patterson, " "	78 46.1	75 30.5	5 02 02
Camp Separation, Smith Sound	78 52 55	- - - - - - - -	- - - - - - -
Foggy Camp, " "	- - - - - - - -	71 28	4 45 52
Camp Frazer, " "	80 06.3	- - - - - - - -	- - - - - - -
Farthest Camp, Kennedy Channel	81 31.5	- - - - - - - -	- - - - - - -
Camp Leidy, Smith Sound	79 58.5	- - - - - - - -	- - - - - - -
Deep Snow Camp, " "	79 54.8	- - - - - - - -	- - - - - - -
Camp Hawks,[2] " "	79 43.7	73 06	4 52 24
Scouse Camp, " "	79 29.0	- - - - - - - -	- - - - - - -
Netlik, Whale Sound	77 07.8	71 22.0	4 45 28
Upernavik, Upper Baffin Bay	72 46 37	- - - - - - - -	- - - - - - -
Pröven, Governor's house	72 23 01	55 32 45	3 42 11

[1] I suspect that the above times were noted by the pocket chronometer, and not by 2007. I have, therefore, subtracted $2^m\ 22^s$ to refer to 2007.

[2] On the unrevised track chart of Dr. Kane's the cape, forming the southern promontory of Dobbin Bay, is named after Dr. I. I. Hayes; but on the chart accompanying Dr. Kane's narrative of his expedition (see Vol. I) the cape appears as Cape Hawks, and the more northern and eastern cape, where Dr. Hayes first made the west coast of Smith Sound, is inscribed with the discoverer's name. This last designation was retained on the Smithsonian chart accompanying the astronomical observations of the Kane expedition, and is adhered to now with the approval of Dr. Hayes.

PENDULUM EXPERIMENTS.

The pendulum observations were made for the purpose of ascertaining the relative force of gravity at Cambridge, Massachusetts, and at the winter quarters of the expedition in North Greenland. The pendulum was expressly made for the occasion by Bond & Son, Boston. It is an invariable, reversible, brass pendulum, perfectly symmetrical in all its parts, as shown in the annexed figure. It is very nearly synchronous, though not convertible, as its form at once indicates. Its total length is 5 feet $7\frac{3}{4}$ inches, width 1.4, and thickness 0.7 inches; distance between the knife-edges 39.4 inches. The steel knife-edges are 14.2 inches from the ends of the bar, 3 inches long, 0.3 inches high, and 0.27 inches wide at the base; their section is triangular. The weight is 21.92 pounds, hence its specific gravity $8\frac{1}{2}$ nearly. The knife-edge, which runs through a perforation of the bar, rests upon steel plates. They are screwed to a brass plate, and supported by a heavy block of wood, which is fastened to the case in which the pendulum swings. There is no adjustment for horizontality of the supporting steel plates other than what is given by the vertical position of the case. The arc of vibration is read off on a scale at the bottom of the case, which has a glass door in front permitting a view of the whole pendulum. Two thermometers are permanently fastened inside the box, one just above the support, the other on a level with the swinging knife-edge.

$\frac{1}{10}$ of real size.

There is a preliminary reduction of the observations at both stations by Mr. Sonntag; the present independent reduction differs from it by a more complete and critical use of the materials; no attempt, however, of combining the resulting number of vibrations at the two stations had been made by Mr. Sonntag.

The following explanatory note is extracted from the record of the experiments at the Harvard College Observatory:—

"Pendulum suspended in transit room of Observatory of Harvard College, Cambridge, and its vibrations observed by G. P. Bond, Director, and T. H. Safford, Assistant."

In the following pages are the times read off from the record sheet of the electric register. The signals always commence with the transit of a mark on the pendulum from *right* to *left*, seen in the telescope (which does not invert). Different marks were used for different sets,[1] but the same mark was always observed both right (R.) and left (L.).

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[1] Owing to defective illumination the point first selected, which was the knife-edge, could not always be seen, and others were taken—all of them near the axis.

The pendulum vibrates nearly at mean solar time, temperature at 71° Fah.

The register clock gained daily $2^s.9$ on sidereal time.

The "arc" denotes the angle between the extreme right and left positions of the pendulum.

The geological formation is drift overlying the silurian rocks.

Pendulum Experiments.

Vibrations observed at the Observatory of Harvard College, Cambridge, Massachusetts, July 3 and 4, 1860.[1]

G. P. Bond, Director of Observatory, observer.

July 3, 1860. No. 4 faces telescope and swings.

R.
$13^h\ 57^m\ 15^s.2$ at $12^h\ 5^m$ upp. ther. 72°.8 F.
17.2 low. " 69.8
19.2 observer, G. P. B.
21.2
23.2 ×
25.2
27.2
29.3
31.2
33.2

L.
13 57 38.2
40.2
42.3
44.3
46.3
48.2 ×
50.2 at $13^h\ 59^m$ arc 3°.10[2]
52.2
54.3
56.3
58.2
58 00.3

R.
14 06 52.8
54.8
56.8
58.8
07 00.8 at $14^h\ 7^m$ arc 2.84
02.9 ×
04.8
06.8
08.8
10.8
12.8
14.8

L.
14 07 17.9
19.9
21.9
23.9
25.9
27.9 ×

$14^h\ 07^m\ 29^s.9$
31.9
33.9
36.0
37.9

R.
15 03 34.0 at $15^h\ 4^m$ upp. ther. 71.8
36.0 low. " 69.8
38.0 arc 1.50
40.0
42.0
44.0
46.0 ×
48.1
50.1
52.1
54.0
56.1
58.0

L.
15 04 23.2
25.2
27.3
29.3
31.2
33.2
35.2 ×
37.3
39.3
41.3
43.3
45.3
47.3
49.3

R.
16 06 04.0 at $16^h\ 7^m$ arc 0.81
06.2 at 16 9 upp. ther. 71°.7
08.1 low. " 69.8
10.2 bar. 20.924 inches
12.2 at. ther. 74° F.
14.1 ×
16.2
18.2
20.2
22.2
24.2

L.
$16^h\ 06^m\ 39^s.3$
41.3
43.3
45.3
47.4
49.4
51.4
53.4
55.4
57.4
59.4 ×
7 01.3
03.4
05.4
07.4
09.4
11.5
13.4
15.5
17.4
19.4

R.
17[3] 09 16.3 at $17^h\ 8^m$ arc 0.48
18.4
20.4
22.4
24.4
26.4 ×
28.5
30.5
32.5
34.5

L.
17[3] 09 51.5
53.5
55.5
57.5
59.5
10 01.6
03.6
05.6 ×
07.6
09.7
11 6
13.6
15.5
17.6

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[1] Some experiments made July 2d and 3d, with knife edges No. 3 and No. 1 facing the telescope and swinging, are here omitted. It was found, after reversing the pendulum end for end, that the wooden case interfered with the free action of the pendulum (in position, side No. 4 facing the telescope and swinging). The case was screwed closer to the wall, altering by 1° or 2° the inclination to horizontal plane of the faces on which the knife edges rest when pendulum is oscillating.

[2] Recorded 2°.10.

[3] Recorded 16^h

R.
$17^h\ 56^m\ 34^s.0$ at $17^h\ 56^m$ arc 0.33
36.1 at 17 59 upp. ther. 70°.8
38.1 low. " 68.7
40.1 bar. 29.901
42.2 at. ther. 73
44.2
46.1
48.1 ×
50.2
52.1
54.2
56.2
58.2
7 00.0

L.
17 57 09.3
11.2
13.2
15.2
17.2
19.2
21.2
23.2
25.2
27.2
29.2
31.2 ×
33.2
35.2
37.3
39.2
41.2
43.2
45.2
47.2
49.2
51.2 Stopped for the night.
July 3 (4th) 1860. Found pendulum still vibrating at 7 A. M.
Reversed to face No. 2.

R.
3 02 38.8 at $2^h\ 50^m$ upp. ther. 68°.6
40.8 " low. " 67.2
42.8 bar. 29.812
44.8 at. ther. 71
46.9 × at $3^h\ 0^m$ arc 3.82
48.9 observer, G. P. B.
50.9
52.9
54.8
56.8

L.
3 03 07.9
09.9
11.8
13.8
15.8
17.9
19.9
21.9 ×
23.9
25.9
27.9
29.9
31.9
33.9
35.9
38.0

R.
3 05 17.3
19.3
21.3
$3^h\ 05^m\ 23^s.2$
25.3
27.3 ×
29.3
31.2
33.3
35.3
37.3
39.3

L.
3 05 46.3
48.3
50.3
52.3
54.3
56.3 ×
58.3
06 00.3
02.3
04.3
06.4
08.3 at $3^h\ 07^m$ arc 3.46

R.
3 13 46.6
48.6
50.6
52.6
54.7
56.6
58.7
14 00.7 ×
02.6
04.7
06.7
08.7
10.7
12.7
14.7

L.
3 14 19.7
21.7
23.6
25.7
27.7
29.7
31.7
33.7
35.8
37.6 ×
39.8
41.7
43.7
45.7
47.7
49.8
51.7
53.7
55.7 at $3^h\ 16^m$ arc 3.09

R.
4 22 29.7 at $4^h\ 20^m$ upp. ther. 69°.2
31.7 " low. 67.5
33.7
35.7
37.7
39.7
41.7
43.6 ×
45.7
47.6
49.7
51.6
53.8
55.6

L.
$4^h\ 23^m\ 10^s.7$
12.6
14.6
16.6
18.6
20.6
22.6
24.7 ×
26.7
28.7
30.7
32.7
34.7
36.7
38.6 at $4^h\ 25^m$ arc 1.39

R.
4 26 28.2
30.3
32.3
34.3 ×
36.4
38.3

L.
4 26 45.3
47.3
49.3
51.3 ×
53.3
55.3

R.
5 38 57.7
59.7
39 01.7
03.6
05.6
07.6 ×
09.6
11.6
13.6
15.7
17.7

L.
5 39 22.8 at $5^h\ 40^m$ arc 0.72
24.8
26.7
28.8
30.8
32.8 ×
34.8
36.8
38.8
40.8

R.
6 19 52.0
54.0
56.0
58.0
20 00.0
02.0 ×
04.1
06.0
08.1
10.1

L.
6 20 15.2
17.1
19.1
21.2
23.1
25.1 ×

$6^h\ 20^m\ 27^s.2$
29.1 at $6^h\ 21^m$ arc 0.50
31.1 upp. ther. 71.3
33.2 low. " 70.4

R.
7 07 59.6
08 01.5
03.6
05.6
07.6
09.6 ×
11.6
13.7
15.7
17.6
19.7

L.
7 08 24.7
26.7
28.7
30.7 at $7^h\ 9^m$ arc 0.33
32.7 upp. ther. 72.5
34.7 × low. " 72.0
36.8 at $7^h\ 19^m\ 40^s.0$ the vibra-
38.8 tion of pendulum was
40.8 from left to right, the
42.7 central transit occur-
44.8 ing at the even second.
Reversed to No. 1.

R.
7 24 48.1 Pendulum was reversed
50.1 at about $7^h\ 10^m$; face
52.1 No. 1 swinging and
54.1 towards the telescope.
56.1
58.1
25 00.2 × observer, G. P. B.
02.1
04.1
06.1
08.1
10.2
12.2

L.
7 25 17.1 at $7^h\ 25^m$ arc 4°.45
19.1
21.0
23.2
25.1 ×
27.2
29.2
31.1
33.2
35.2

R.
7 27 24.6
26.5
28.5 ×
30.5
32.5
35.5[1]
37.6
39.6
41.6
43.5 ×
45.6
47.6
49.6
51.5

R.
7 30 31.0 at $7^h\ 29^m$ arc 4.30
33.0
35.0

$7^h\ 30^m\ 37^s.0$
39.0 ×
41.0
43.1
45.0
47.0

L.
7 30 50.0 at $7^h\ 30^m$ arc 4.17
52.0
54.0
56.1
58.0 ×
31 00.0
02.1
04.0
06.0
08.1

R.
7 38 32.3 at $7^h\ 38^m$ arc 3.62
34.3 ×
36.3

L.
7 38 41.3 at $7^h\ 39^m$ upp. ther. 73°.3
43.4 × low. " 72.9
45.4

R.
12 14 35.9 at $12^h\ 08^m$ arc 0.26
38.0 at 12 14 upp. ther. 73.2
40.0 " low. " 72.3
42.0
44.0
46.1
48.0
50.0 ×
52.0
54.0
56.1
58.0
15 00.0
02.0
04.0

L.
12 15 13.0
14.9
17.0
19.0
21.0
22.9
25.0
27.0
29.0 ×
31.0
33.0
35.0
37.1
39.0
41.0
43.0

R.
12 17 48.5
50.5
52.5
54.5 ×
56.5
58.6
18 00.5

L.
12 18 07.4
09.4
11.4
13.4

$12^h\ 18^m\ 15^s.5$
17.6 ×
19.6
21.7
23.6
25.6
27.5

R.
12 22 27.1
29.2
31.2 ×
33.2
35.2

L.
12 22 42.1
44.2
46.2
48.2
50.3 ×
- - - at $12^h\ 24^m$ upp. ther. 72°.8
54.2 " low. " 71.9
56.2 bar. 29.790
58.2 at. ther. 74
Reversed to face No. 3, swinging and towards the telescope.

R (?)[2] observer, G. P. B.
12 56 21.0
23.0
25.0 ×
27.0
29.0
31.1

L (?)[2]
12 56 38.0
40.0
42.1 ×
44.0
46.1
48.0

R.
16 19 48.7 at $16^h\ 15^m$ upp. ther. 70°.2
50.7 " low. " 69.0
52.7 × arc 0.43
54.7
56.7
58.7

L.
16 20 03.6
05.6
07.6 ×
09.6
11.6

R.
17 18 21.6 at $17^h\ 18^m$ arc 0.25
23.7
25.6 ×
27.6
29.6

L.
17 18 32.7 upp. ther. 70°.0
34.7 low. " 68.9
36.7 × bar. 29.830
38.7 at. ther. 71.
40.7

N. B. The last sets of observations, face Nos. 1 and 3, were taken without any alterations of the case from its position for Nos. 2 and 4.

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[1] Should be L.

[2] As assumed by Mr. Sonntag; left blank in MS. To judge from the rate of the clock it should be L. and R. [SCH.]

FORMULÆ AND METHOD OF REDUCTION.

To render the results obtained at different places comparable with each other, the observed number of vibrations require the following corrections, that for rate of clock having first been applied.

Reduction to Infinitely Small Arc.

The duration of a vibration in any small arc is always greater than in an infinitely small arc, the correction to the observed number of vibrations is therefore additive.

Let $A =$ the initial semi-arc of vibration

$a =$ the terminal semi-arc of vibration

$N =$ number of vibrations in a given time;

then the correction $= N \dfrac{M \sin (A+a) \sin (A-a)}{32 (\log. \sin A - \log. \sin a)} = N \dfrac{M \sin^2 1°}{32} \cdot \dfrac{A^2 - a^2}{\log. A - \log. a}$

At Cambridge the number, N, of vibrations in a mean solar day is about 86420, at Port Foulke about 86550, and since M, the logarithmic modulus $= 0.4342945$, the logarithm of the factor $N \cdot \dfrac{M \sin^2 1°}{32}$ becomes [9.55295] and [9.55361] respectively for these localities.

Correction for Temperature of Pendulum.

For a higher temperature than the adopted standard temperature, the pendulum becomes longer, and the number of vibrations are diminished; the correction to N is therefore positive, for a lower temperature than the standard temperature, the correction is negative.

Let $e =$ coefficient of expansion of the material of the pendulum bar

$t =$ observed temperature

$t_0 =$ standard temperature

then the correction $= N \dfrac{e}{2} (t - t_0)$

The average temperature of the pendulum, when swung at Cambridge, was about 71°, and at Port Foulke about 23° Fah. I have therefore adopted 50° Fah. as a convenient standard temperature.

Reliable determinations of e for 1° Fah. seem to vary between 0.0000104 and 0.0000105, taking the mean and using N as above we find for the coefficient of $t - t_0$ the value 0.4511 for Cambridge, and 0.4518 for Port Foulke, or the logarithmic factors [9.65428] and [9.65494] respectively

Correction for Buoyancy.

As the pendulum was not swung in a rarified medium to ascertain the correction for buoyancy and resistance experimentally, we use the coefficient determined by Bailey (see Vol. VII, p. 27, Memoirs Royal Astronomical Society).

Let β = reading of barometer in inches, and reduced to 32° Fah.

t = temperature of the air in degrees of Fah.; then the correction to the number of vibrations made in a mean solar day by a brass pendulum

$$= 0.3541 \frac{\beta}{1 + 0.0023\ (t - 32)}$$

The average reading of the barometer (reduced to 32°) at Cambridge is $29^{in}.72$, and at Port Foulke $29^{in}.82$, the observations have therefore been referred to the convenient average reading $29^{in}.8$ by the formula

$$\frac{0.3541\ (\beta - \beta_0)}{1 + 0.0023\ (t - 32)}$$

The average t at Cambridge is 70°.9, and at Port Foulke + 22°.8 hence the correction for Cambridge 0.325 (β — 29.8), and for Port Foulke 0.362 (β — 29.8). The reduction to vacuum is always additive. The variations from the average t at either place are small.

Reduction to the Level of the Sea.

Let N = number of vibrations at the elevated station

N_1 = corresponding number at the sea level

H = the elevation and R = the earth's radius, then the reduction to the number of vibrations in a day (see Vol. VII, p. 28, Mem. Roy. Ast. Soc.) $= 0.666\ N \frac{H}{R}$ a correction which is always additive. For Cambridge we have 0.00276 H, and for Port Foulke 0.00277 H, the elevation, above half tide being expressed in feet.

From the preceding record the following abstract of observed times, arcs, temperatures and atmospheric pressure has been formed.

The first column contains the number of observed times united into a mean; the second column the average clock times of vibrations from right to left; for an odd number of times the mean corresponding to the middle one is set down; for an even number either the first or last observation was omitted; the middle times, in all cases are marked thus × in the preceding record; the third column contains the arcs of vibration; when not directly observed they were interpolated by a graphical process, the arcs are inversely as the squares of the times, and the curves constructed on a sufficiently large scale proved them to be quite smooth and regular; the fourth column contains the average temperatures observed or interpolated. The next column contains similar information for vibrations from left to right, and the last column gives the observed height of the barometer when referred to temperature 32° Fah.

The first means for face 3 have been corrected by subtracting one second to refer to "right" and "left" respectively.

Reduction of Pendulum Experiments made in July, 1860, at Cambridge, Mass.

Ob's.	Clock times, R.	Arc.	Temp.	Ob's.	Clock times, L.	Arc.	Bar.
			Face 4.				
9	13h 57m 23s.21	3°.15	71°.3	11	13h 57m 48s.25	3°.15	
11	14 07 02.81	2.84	71.2	11	14 07 27.91	2.84	
13	15 03 46.03	1.50	70.8	13	15 04 35.26	1.50	
11	16 06 14.16	0.81	70.7	21	16 06 59.38	0.81	29.80
9	17 09 26.43	0.48	70.1	13	17 10 05.57	0.48	
13	17 56 48.14	0.33	69.7	21	17 57 31.20	0.33	29.78
			Face 2.				
9	3 02 46.84	3.70	67.9	15	3 03 21.88	3.65	29.70
11	3 05 27.28	3.53	68.0	11	3 05 56.31	3.50	
15	3 14 00.66	3.15	68.2	19	3 14 37.71	3.15	
13	4 22 43.68	- - -	68.3	15	4 23 24.65	- - -	
5	4 26 34.32	- - -	- - -	5	4 26 51.30	- - -	
11	5 39 07.65	0.72	70.0	9	5 39 32.79	0.72	
9	6 20 02.03	0.50	70.8	9	6 20 25.13	0.50	
11	7 08 09.62	0.33	72.2	11	7 08 34.74	0.33	
			Face 1.				
13	7 25 00.12	4.45	72.7	9	7 25 25.13	4.45	
5	7 27 28.52	4.30	72.8	9	7 27 43.57	4.30	
9	7 30 39.01	4.17	72.9	9	7 30 58.02	4.17	
3	7 38 34.30	- - -	73.1	3	7 38 43.37	- - -	
15	12 14 50.00	0.25	72.7	15	12 15 28.99	0.25	
7	12 17 54.51	0.23	72.9	11	12 18 17.52	0.23	
5	12 22 31.18	0 20	72.3	9	12 22 50.21	0.20	29.67
			Face 3.				
5	12 56 25.00 } — 1.00 }	3.40	72.0	5	12 56 42.04 } — 1.00 }	3.40	
5	16 19 52.70	0.40	69.6	5	16 20 07.60	0.40	
5	16 18 25.62	0.25	69.4	5	17 18 36.70	0.25	29.72

The following reduction gives, in the first place, the intervals of the clock times obtained, for face 4, by subtracting the first mean from the fourth, the second from the fifth, and the third from the sixth; for face 2 by omitting the means at 4 hours as they will contribute almost nothing to the accuracy of the result, and then proceeding as in the preceding case for face 4; for face 1 by the same treatment after omitting the central mean, and for face 3 by subtracting the first from the second and third means.

These clock intervals are next reduced to mean time intervals by application of a correction for rate (r). It was found convenient to apply this correction separately for rate of clock on sidereal time, for which purpose a small table was computed extending to 5 hours, and secondly for acceleration of sidereal on mean time.

The mean time intervals, expressed in seconds, are followed by the corresponding number of vibrations performed in the intervals from which, by proportion, the number of vibrations N performed in a day are computed. The corrections for arc, temperature, and atmospheric pressure were computed by the formulæ given above.

Clock intervals.	Correction for rate.	Mean time intervals.	Number of vibr's.	Corres. No. in a day.	Corrections for Arc.	Temp.	Atm. pr.	N
			Face	4.				
Vibr's right								
2^h 08^m $50^s.95$	—21.^{s}37	7709^s.58	7710	86404.71	+1.39	+9.47	.00	86415.57
3 02 23.62	—30.23	10913.39	10914	86404.80	+0.91	+9.29	"	15.00
2 53 02.11	—28.68	10353.43	10354	86404.74	+0.30	+9.11	"	14.15
Vibr's left								
2 09 11.13	—21.42	7729.71	7730	86403.24	+1.39	+9.47	"	86414.10
3 02 37.66	—38.28	10927.38	10928	86405.92	+0.91	+9.29	"	16.12
2 52 55.94	—28.67	10347.27	10348	86406.10	+0.30	+9.11	"	15.51
							Mean	86415.07
			Face	2.				
Vibr's right								
2 36 20.81	—25.92	9354.89	9356	86410.26	+1.66	+8.57	—.03	86420.46
3 14 34.75	—32.26	11642.49	11644	86411.20	+1.29	+8.75	"	21.21
3 54 08.96	—38.83	14010.13	14012	86411.54	+0.91	+9.11	"	21.53
Vibr's left								
2 36 10.91	—25.89	9345.02	9346	86410.68	+1.62	+8.57	—.03	86420 84
3 14 28.82	—32.25	11636.57	11638	86410.62	+1.27	+8.75	"	20.61
3 53 57.03	—38.80	13998.23	14000	86411.83	+0.91	+9.11	"	21.82
							Mean	86421.08
			Face	1.				
Vibr's right								
4 49 49.88	—48.06	17341.82	17344	86410.86	+1.42	+10.24	—.04	86422.48
4 50 25.99	—48.16	17377.83	17380	86410.78	+1.31	+10.28	"	22.33
4 51 52.17	—48.39	17463.78	17466	86410.98	+1.17	+10.19	"	22.30
Vibr's left								
4 50 03.86	—48.10	17355.76	17358	86411.16	+1.42	+10.24	"	86422.78
4 50 33.95	—48.18	17385.77	17388	86411.06	+1.31	+10.28	"	22.61
4 51 52.19	—48.39	17463.80	17466	86410.90	+1.17	+10.19	"	22.22
							Mean	86422.45
			Face	3.				
Vibr's right								
3 23 28.70	—33.74	12174.96	12176	86407.38	+1.10	+9.38	—.04	86417.82
4 22 01.62	—43.44	15678.18	15680	86410.02	+0.68	+9.34	"	20.00
Vibr's left								
3 23 26.56	—33.74	12172.82	12174	86408.36	+1.10	+9.38	"	86418.80
4 21 55.66	—43.42	15672.24	15674	86409.68	+0.68	+9.34	"	19.66
								86419.07

We have therefore the following resulting number of vibrations performed at Cambridge in a mean solar day, the temperature of the pendulum being 50° Fah., and the atmospheric pressure 29.8 inches (with the mercury at the temperature of freezing water),

First position of pendulum.		After reversal, end for end.	
Face 4 swinging,	86415.07	Face 1 swinging,	86422.45
" 2 "	86421.08	" 3 "	86419.07
Mean,	86418.08	Mean,	86420.76

Mean of two positions 86419.42
Correction for 80[1] feet elevation above half tide + ...22

Resulting number of vibrations at the level of the sea in the latitude of Cambridge 86419.64

The Cambridge Observatory is in latitude 42° 22′ 51″.5

Observations connected with Pendulum Experiments at Port Foulke.

The following observations for local time at Port Foulke were taken for the special purpose of furnishing the chronometer rate required for the pendulum experiments. The observed double altitudes of α Lyræ, September 22d and October 17th, 1860, given in the preceding part of the astronomical record, belong to the same series.

Observations for time, October 1, 1860.

Double altitudes of α Lyræ, with reflecting circle. A. Sonntag, observer.

Index $\begin{cases} +1'\ 20'' & +1'\ 30'' & +1'\ 20'' \\ +1\ \ 00 & +1\ \ 10 & +1\ \ 50 \end{cases}$ Correction + 1′ 11″.7

Pocket chronometer	2*		Pocket chronometer	2*	
10h 34m 08s	87° 53′	40″, 30	10h 44m 03s	86° 56′	40″, 40
35 20	46	40, 10	44 57	51	20, 00
36 09	41	30, 20	46 04	44	60, 40
37 08	35	30, 20	47 18	37	60, 30
38 08	30	40, 10	48 09	32	80, 50
38 57	24	50, 40	49 02	26	50, 40
39 57	20	50, 30	49 44	23	40, 40
40 55	15	20, 10	50 28	19	40, 30
42 13	08	20, 10	51 55	11	60, 30
43 08	01	60, 50	52 49	05	40, 40

T = + 16°.5, B = 29in.693 at 20° Index $\begin{cases} +1'\ 10'' & +1'\ 20'' & +1'\ 20'' \\ +1\ \ 00 & +1\ \ 00 & +1\ \ 00 \end{cases}$ Corr'n + 1′ 08″.3

(As in preceding cases, the observations were combined two by two.)

Refr'n for first pair — 1′ 04″.7, for last —1′ 06″.6
*'s declination $\delta = +38° 39' 35''.4$, right ascension $\alpha = 18^h 32^m 13^s.9$

Sidereal time at mean noon $12^h 42^m 33^s.6$; the sidereal time is converted into mean time, and ΔT is the chronometer correction on mean local time.

[1] Annals of the Observatory, Vol. I, Part I, p. xvi.

T	h	t	ΔT
$10^h\ 34^m\ 44^s$	43° 54′ 30″	58° 54′ 40″	$-51^m\ 01^s$
10 36 38.5	43 48 43	59 25 25	—50 53
10 38 32.5	43 43 17	59 54 03	—50 53
10 40 26	43 38 28	60 19 23	—51 05
10 42 40.5	43 32 02	60 53 11	—51 05
10 44 30	43 26 27	61 22 25	—50 57
10 46 41	43 20 08	61 55 19	—50 57
10 48 35.5	43 14 26	62 24 54	—50 54
10 50 06	43 10 17	62 46 25	—50 58
10 52 22	43 03 50	63 19 46	—51 01
		Mean . .	$-50\ 58.4 \pm 0^s.9$

Observations for time, October 2, 1860.

Double altitudes of α Lyræ, with reflecting circle. A. Sonntag, observer

$$\text{Index}\left\{\begin{matrix} +0'\ 40'' & +0'\ 40'' & +1'\ 10'' \\ +0\ \ 40 & +0\ \ 30 & +1\ \ 10 \end{matrix}\right\}\ \text{Correction} + 0'\,48''.3$$

Pocket chronometer	2*	Pocket chronometer	2*
$10^h\ 46^m\ 59^s$	86° 04′ {20″ / 30}	$11^h\ 20^m\ 45^s$	82° 43′ {60″ / 50}
48 37	85 54 {60 / 50}	21 41	38 {20 / 00}
50 19	45 {00 / 20}	22 35	32 {40 / 20}
51 31	38 {30 / 20}	23 49	25 {10 / 00}
53 32	25 {30 / 20}	24 37	20 {10 / 00}
54 32	19 {60 / 50}	25 23	15 {40 / 10}
55 35	14 {20 / 20}	26 14	09 {30 / 20}
56 25	09 {30 / 20}	27 35	02 {10 / 10}
57 45	00 {50 / 40}	28 24	81 57 {20 / 10}
58 35	84 55 {70 / 40}	29 46	48 {40 / 30}
11 00 10	47 {20 / 20}	30 38	42 {30 / 10}
01 07	40 {50 / 50}	31 55	35 {30 / 10}
02 10	34 {80 / 50}	32 56	28 {30 / 20}
03 01	29 {30 / 20}	33 39	23 {30 / 40}
03 49	24 {80 / 50}	35 00	17 {60 / 40}
05 06	15 {80 / 40}	35 55	11 {10 / 00}

$$\text{Index}\left\{\begin{matrix} +1'\ 20'' & +1'\ 30'' & +1'\ 20'' \\ +1\ \ 10 & +1\ \ 20 & +1\ \ 00 \end{matrix}\right\}\ \text{Correction} + 1'\,16''.6$$

$T = +13^\circ.6$, $B = 29^{in}.841$ at 27° $\quad\text{Index}\left\{\begin{matrix} +1'\ 10'' & +1'\ 30'' & +1'\ 00'' \\ +1\ \ 10 & +1\ \ 30 & +1\ \ 10 \end{matrix}\right\}$ Corr'n $= +1'\ 15''$

$r = -1'\ 07''.5 \qquad r_1 = -1'\ 13''.3$

$\delta = +38^\circ\ 39'\ 35''.4 \qquad \alpha = 18^h\ 32^m\ 13^s.9$

Sidereal time at mean noon, 12 46 30.2

T	h	t	ΔT
10h 47m 48s	42° 59′ 14″	63° 43′ 30″	—48m 49s
10 50 55	42 50 17	64 29 27	52
10 54 02	42 40 43	65 18 26	44
10 56 00	42 35 19	65 45 57	52
10 58 10	42 28 32	66 20 30	44
11 00 43.5	42 21 24	66 56 42	44
11 02 35.5	42 15 29	67 26 42	46
11 04 27.5	42 09 37	67 56 18	40
11 21 13	41 19 58	72 05 09	53
11 23 12	41 13 58	72 35 39	50
11 25 00	41 08 19	73 03 09	48
11 26 54.5	41 02 20	73 32 53	44
11 29 05.5	40 55 53	74 04 50	48
11 31 16.5	40 48 50	74 39 49	39
11 33 17.5	40 42 25	75 11 34	33 rejected
11 35 27.5	40 36 38	75 40 10	49
		Mean . . .	—48 46.8 ± 0s.7

Observations for time, October 9, 1860.

Double altitudes of α Lyræ, with reflecting circle. A. Sonntag, observer.

$$\text{Index}\begin{Bmatrix} +1'\ 20'' & +1'\ 00'' & +1'\ 10'' \\ +1\ \ 10 & +0\ \ 50 & +0\ \ 50 \end{Bmatrix}\ \text{Correction } +1'\ 3''.3$$

Pocket chronometer	2*	Pocket chronometer	2*
10h 33m 42s	84° 40′ {20″, 30}	10h 50m 08s	83° 02′ {20″, 20}
34 32	36 {20, 20}	50 54	82 57 {20, 20}
35 29	30 {40, 40}	51 43	53 {20, 30}
36 17	25 {40, 30}	52 35	48 {10, 10}
37 10	20 {40, 40}	53 31	43 {20, 00}
38 17	14 {40, 30}	54 26	36 {30, 00}
39 37	5 {50, 50}	55 45	28 {40, 20}
40 40	83 59 {20, 30}	56 37	23 {10, 20}
41 46	52 {40, 20}	57 22	18 {40, 50}
42 52	47 {00, 00}	58 12	13 {40, 20}
43 47	40 {40, 40}	59 13	7 {30, 40}
45 18	30 {40, 40}	11 00 02	2 {20, 30}
46 01	26 {20, 40}	0 55	81 57 {10, 00}
46 52	22 {20, 30}	1 43	52 {30, 10}
47 53	15 {60, 40}	2 43	45 {20, 40}
48 42	10 {50, 50}	3 36	41 {20, 20}

Roof of artificial horizon reversed.

$T = +19°.5$, $B = 30^{in}.072$ at 30° $\text{Index}\begin{Bmatrix} +2'\ 10'' & +1'\ 50'' & +1'\ 40'' & +1'\ 40'' \\ +2\ \ 20 & +1\ \ 50 & +1\ \ 50 & +1'\ 40 \end{Bmatrix}$ Corr'n $+1'\ 52''.5$

$r = -1'\ 08''.7$ $\qquad r_1 = -1'\ 12''.3$

$\delta = +38°\ 39'\ 35''.3$ $\qquad \alpha = 18^h\ 32^m\ 13^s.7$

Sidereal time at mean noon, $\quad$ 13 14 06.1

T	h	t	ΔT
$10^h\ 34^m\ 07^s$	42° 18′ 46″	67° 10′ 00″	$-48^m\ 56^s$
35 53	42 13 39	67 35 57	58
37 43.5	42 08 24	68 02 29	63
40 08.5	42 00 53	68 40 18	57
42 19	41 54 29	69 12 28	59
44 32.5	41 47 24	69 48 04	50
46 26.5	41 41 48	70 16 10	52
48 17.5	41 36 14	70 44 01	52
50 31	41 29 28	71 17 46	51
52 09	41 24 57	71 40 21	59
53 58.5	41 19 24	72 07 58	58
56 11	41 12 29	72 42 24	53
57 47	41 07 36	73 06 42	53
59 37.5	41 02 02	73 34 09	54
11 01 19	40 56 53	73 59 53	52
03 09.5	40 51 14	74 27 53	51
		Mean . . .	$-48\ 54.9 \pm 0^s.6$

Observations for time, October 10, 1860.

Double altitudes of α Lyræ, with reflecting circle. A. Sonntag, observer.

Index $\begin{cases} +1'\ 40'' & +1'\ 20'' & +0'\ 40'' \\ +1\ 30 & +1\ 00 & +0\ 40 \end{cases}$ Correction $= +1'\ 08''.3$

Pocket chronometer	2*	Pocket chronometer	2*.
$10^h\ 54^m\ 47^s$	82° 11′ $\begin{cases} 20'' \\ 00 \end{cases}$	$11^h\ 05^m\ 38^s$	81° 03′ $\begin{cases} 40'' \\ 40 \end{cases}$
56 01	4 $\begin{cases} 20 \\ 00 \end{cases}$	7 15	80 54 $\begin{cases} 20 \\ 20 \end{cases}$
58 55	81 45 $\begin{cases} 40 \\ 20 \end{cases}$	8 16	48 $\begin{cases} 00 \\ 00 \end{cases}$
59 52	39 $\begin{cases} 60 \\ 40 \end{cases}$	9 51	39 $\begin{cases} 20 \\ 10 \end{cases}$
11 00 43	33 $\begin{cases} 60 \\ 50 \end{cases}$	10 54	33 $\begin{cases} 30 \\ 10 \end{cases}$
1 46	29 $\begin{cases} 10 \\ 10 \end{cases}$	11 45	27 $\begin{cases} 20 \\ 20 \end{cases}$
3 14	19 $\begin{cases} 40 \\ 50 \end{cases}$	12 41	21 $\begin{cases} 20 \\ 30 \end{cases}$
4 19	12 $\begin{cases} 60 \\ 40 \end{cases}$	13 35	16 $\begin{cases} 20 \\ 00 \end{cases}$

T = + 12°.5, Bar. $30^{in}.050$ at 25° Index $\begin{cases} +1'\ 30'' & +1'\ 20'' & +0'\ 50'' \\ +1\ 20 & +1\ 20 & +0\ 40 \end{cases}$ Correction + 1′ 10″

$r = -1'\ 12''.9$ $r_1 = -1'\ 15''.3$

$\delta = +38°\ 39'\ 35''.2$ $\alpha = 18^h\ 32^m\ 13^s.7$

Sidereal time at mean noon, 13 18 02.6

T	h	t	ΔT
$10^h\ 55^m\ 24^s$	41° 03′ 12″	73° 28′ 34″	$-48^m\ 58^s$
59 23.5	40 50 41	74 30 37	50
11 01 14.5	40 45 07	74 58 11	51
03 46.5	40 37 29	75 35 58	53
06 26.5	40 28 50	76 18 44	42
09 03.5	40 21 09	76 56 43	48
11 19.5	40 14 30	77 29 33	52
13 08	40 08 43	77 58 03	47
		Mean . . .	$-48\ 50.1 \pm 1^s.1$

Recapitulation of observed correction of Pocket Chronometer at Port Foulke, in connection with Pendulum Experiments.

	T					ΔT on mean time.		
1860.	September	22 at	11^h	chronometer	time	-50^m	$43^s.3$	$\pm 0^s.9$
1860.	October	1	11	"	"	—50	58.4	0.9
1860.	October	2	11	"	"	—48	46.8	0.7
1860.	October	9	11	"	"	—48	54.9	0.6
1860.	October	10	11	"	"	—48	50.1	1.1
1860.	October	17	10	"	"	—48	58.5	0.7

The chronometer changed its correction about $2^m.2$ between 9 A. M. and 3 P. M., October 2d; retarded or stopped in consequence of a hair having become entangled in one of the hands.

The actual rate of the pocket chronometer, during the pendulum experiments, is found by means of comparisons of the pocket chronometer with three mean time chronometers; comparisons were made at the beginning and end of each daily set of pendulum experiments.

Chronometer comparisons for correction and rate of mean time chronometers 2007, 1062, and 740. (Those for September 22d have already been given.)

October 1, 1860.

Pocket chronometer.	Mean time.	Chronometers.	ΔT at Port Foulke.
11^h 25^m $24^s.0$	10^h 34^m $25^s.6$	2007 : 3^h 26^m	-4^h 51^m $34^s.4$
26 54.0	10 35 55.6	1062 : 3 25	—4 49 04.4
28 31.2	10 37 32.8	740 : 3 27	—4 49 27.2

October 2, 1860.

Pocket chronometer.	Mean time.	Chronometers.	ΔT	
11^h 02^m $15^s.3$	10^h 13^m $28^s.5$	2007 : 3^h 05^m	-4^h 51^m $31^s.5$	Two sets of comparisons were taken, according within a fraction of a second. The value given is the mean.
2 43.5	10 13 56.7	1062 : 3 03	—4 49 03.3	
4 21.0	10 15 34.2	740 : 3 05	—4 49 25.8	

October 9, 1860.

Pocket chronometer.	Mean time.	Chronometers.	ΔT	
10^h 39^m $02^s.0$	9^h 50^m $07^s.1$	2007 : 2^h 41^m	-4^h 50^m $52^s.9$	Two sets of comparisons were taken; they do not differ by more than $0^s.2$.
39 41.9	9 50 47.0	1062 : 2 40	—4 49 13.0	
41 21.9	9 52 27.0	740 : 2 42	—4 49 33.0	

October 10, 1860.

Pocket chronometer.	Mean time.	Chronometers.	ΔT	
10^h 52^m $04^s.0$	10^h 03^m $13^s.9$	2007 : 2^h 54^m	-4^h 50^m $46^s.1$	Two sets were taken; greatest difference $0^s.4$; the mean is here given.
52 42.2	10 03 52.1	1062 : 2 53	—4 49 07.9	
53 22.5	10 04 32.4	740 : 2 54	—4 49 27.6	

October 17, 1860.

Pocket chronometer.	Mean time.	Chronometers.	ΔT	
10^h 05^m $23^s.0$	9^h 16^m $24^s.5$	2007 : 2^h 7^m	-4^h 50^m $35^s.5$	Mean of two sets; values do not differ by more than a fraction of a second.
06 51.4	9 17 52.9	1062 : 2 7	—4 49 07.1	
07 32.1	9 18 33.6	740 : 2 8	—4 49 26.4	

October 31, 1860. ΔT Pocket chronometer -49^m $15^s.2 \pm 0^s.7$.

Pocket chronometer.	Mean time.	Chronometers.	ΔT
9^h 24^m $50^s.0$	8^h 35^m $34^s.8$	2007 : 1^h 26^m	-4^h 50^m $25^s.2$
25 53.6	8 36 38.4	1062 : 1 26	—4 49 21.6
26 39.0	8 37 23.8	740 : 1 27	—4 49 36.2

If we combine the values of ΔT for October 1 and October 2, viz: —$4^h\ 51^m\ 33^s.0$, —$4^h\ 49^m\ 03^s.8$, —$4^h\ 49^m\ 26^s.5$ respectively, also the values for October 9 and October 10, viz: —$4^h\ 50^m\ 49^s.5$, —$4^h\ 49^m\ 10^s.5$, —$4^h\ 49^m\ 30^s.3$ respectively, we deduce the following table of daily rates:—

Daily rate of mean time chronometers.

	2007	1062	740
1860. September 22, 17^h chronometer time	$+2^s.64$	$+0^s.88$	$+0^s.86$
1860. October 2, 3 " "	$+5.44$	-0.84	-0.47
1860. October 10, 3 " "	$+1.88$	$+0.45$	$+0.52$
1860. October 17, 14 " "	$+0.74$	-1.04	-0.70
1860. October 31, 13 " "			

PENDULUM EXPERIMENTS AT PORT FOULKE.

Explanatory Remarks and Record of Observations.

The pendulum was swung at the Port Foulke Observatory on the same knife edges as at Cambridge, the experiments extending over fourteen days between September 26th and October 12th, 1860. These observations were made by Mr. August Sonntag, assisted by Mr. H. Radcliff. The initial letters of the observer's name are attached to each set of experiments. The following information is taken from notes made by Mr. Sonntag. "From a preliminary set of observations on the morning of September 26th, it was found that at a temperature of 22° Fah. the pendulum made very nearly 3607 vibrations in 3600 seconds of the pocket chronometer.

The time was noted when the swinging knife-edge passed the zero of the graduated arc. The pendulum being at rest, this zero appeared 0°.05 to the right (in an inverting telescope) of the point of the knife-edge, producing a small difference in the intervals when the pendulum was swinging from left to right and when swinging in the opposite direction; the mean of the intervals, however, is not affected thereby.

The observations were always commenced with a set marked 'Left,' the pendulum when seen through the inverting telescope appearing to swing from left to right; immediately after a set is taken with the pendulum appearing in the opposite direction marked 'Right.' Each set consists generally of eleven observations at intervals of ten seconds, the mean is given at the bottom. The times are recorded by means of the pocket chronometer. The semi-arcs are recorded, counted from the middle either way. The azimuth of the plane of vibration was nearly N. W. and S. E."

The following description of the Observatory was received from Dr. Hayes: The Port Foulke Observatory was a small frame structure, eight feet square, by seven feet high in the centre, the roof pitching only one way. It was covered on the outside with canvas, and was lined internally with bear, seal, and other skins. To give greater warmth and solidity the snow was, during the winter, banked up around it, covering it almost completely. It was erected on the first of a series of terraces which lay northeast from the anchorage, and its foundation was thirty-eight feet above the mean tidal level. The rock on which it stood was primitive (a dark reddish-brown syenite), which rose on either side of the harbor into hills from six

to eight hundred feet high. It faced to the southwest, its axis being nearly in the magnetic meridian.

The pendulum apparatus was erected in the autumn. The foot of the box containing it rested upon the solid rock, and the instrument stood in the S. E. (mag.) corner, facing N. W. (mag.).

Experiments, set 1, face 1. September 26th P. M. 1860. Observer, A. Sonntag.

L.	R.	L.	R.	
$2^h\ 48^m\ 29^s.5$	$2^h\ 50^m\ 46^s$	$2^h\ 53^m\ 09^s$	$2^h\ 55^m\ 29^s.8$	at $2^h\ 48^m$ arc $\begin{cases}1^\circ.85\\1.78\end{cases}$
39.0	56	19	39.5	
49.5	06.3	29	49.5	temp. $\begin{cases}27^\circ.5 \text{ Fah.}\\24.5\end{cases}$
59.8	16.5	38.8	00	
09.5	26	48.8	10	bar. $29^{in}.720$ at $29^\circ.5$
19.5	36	58.8	19.8	
29.5	46	09	29.5	
39	56	18.8	39.5	
49	06	28.5	49.5	
59.5	16	38.5	00	at $2^h\ 58^m$ arc $\begin{cases}1^\circ.58\\1.50\end{cases}$
2 50 09.5	2 52 26	2 54 48.5	2 57 10	
2 49 19.39	2 51 36.07	2 53 58.79	2 56 19.74	
2 59 20.4	2 01 23	3 07 31.5	3 09 32	
30.5	33	41.5	42	
40.3	43	51	52	
50 3	53.2	01.3	02	
00.3	03.2	11.5	12.3	
H. R. 10.2	H. R. 13.2	A. S. 21.2	A. S. 22	
20.4	23	31	32	
30.5	33.1	41	42	
40.3	43	51	52	
50.2	53	01	02	
3 1 00.3	3 03 03.2	3 09 11	3 11 12	
3 00 10.34	3 02 13.08	3 08 21.18	3 10 22.03	
6 40 29	6 42 35.5	6 53 19	[1]6 55 14	at $6^h\ 40^m$ arc $\begin{cases}0^\circ.18\\0.12\end{cases}$
38.8	45.5	29.3	24	
48 5	55.3	39	33.8	
58.5	05.3	49	43.5	
09	15.3	59	54	
A. S. 19	A. S. 25	A. S. 09.5	A. S. 04	
28.8	35	19	14	
38.5	45	29	23.5	
48.3	55	39	34	at $6^h\ 57^m$ arc $\begin{cases}0.17\\0.10\end{cases}$
58.5	05	6 54 48.8	6 56 43.5	temp. $\begin{cases}23.3\\22.0\end{cases}$
6 42 09	6 44 15			
6 41 18.72	6 43 25.17	5 54 09.06	6 56 03.83	bar. $29^{in}.810$ at 32.8
6 59 03 0	7 01 05.7	[1] Omitted in mean.	Pock. Chron'r	Chronometer comparisons
13.0	15.6		Deduced hourly rate $= -0^s.30$ (between 3^h and 6^h).	
22.9	25.3			
32.7	35.2			
42.5	45			
H. R. 52.6	H. R. 55.2			
02.8	05.3			
12.8	15.2			
22.7	25.2			
32.3	35			
7 00 42.2	7 02 45			
6 59 52.68	7 01 55.25			

Chronometer comparisons

					No.
A. M.					
$9^h\ 41^m\ 59^s.0$	=	1^h	43^m	by	2007
42 39.8		1	41		1062
43 16.3		1	42		740
P. M.					
3 21 00.2		7	22		2007
21 40.7		7	20		1062
22 17.2		7	21		740
6 03 1.0		10	4		2007
4 42.2		10	3		1062
5 17.8		10	4		740

Set 2, face 1.

L.	R.	L.	R.	
7 26 16	7 28 23	7 30 55.5	7 33 02.5	at 7^h 25^m arc { 1°.52
26.3	33	05.5	12.5	1.42
36	43	15.5	22.3	temp. { 24.3
46	53	26	32.5	23.0
56	03.2	36	42.3	bar. 29^{in}.810 at 32°.0
A. S. 06.2	A. S. 13	A. S. 45.5	A. S. 52	
16	23	55.5	02.5	
26	33	05.8	12.5	
36	42.	15.8	22	
46	52.5	25.3	32	
7 27 56	7 30 03	7 32 35.5	7 34 42.3	at 7^h 35^m arc { 1°.30
				1.22
7 27 06.05	7 29 12.95	7 31 45.63	7 33 52.31	
7 36 51	7 38 54	7 43 08 5	7 45 15	
01.2	04 2	18.5	25	
11.2	14	28	35	
21.2	23.7	38	45	
31	33.7	48.3	55	
H. R. 41	H. R. 43.8	A. S. 58.3	A. S. 05.3	
51	54.0	08.2	15	
01.2	04	18.5	24.8	
11.2	14	28	34.8	at 7^h 48^m arc { 1°.10 / 1.03
21	23.6	38	44.8	temp. { 28°.0 ?
7 38 31	7 40 33.4	7 44 48	7 46 55	25.0
7 37 41.09	7 39 43.86	7 43 58.21	7 46 04.97	
10 46 05	10 48 11.8	10 50 26	10 52 20.5	at 10^h 45^m arc { 0°.19
15	21.5	36	30.8	0.13
25	31.5	46	41	
34.8	41	56	51	
44.8	51.3	06	01	
A. S. 55	A. S. 01.5	A. S. 16.3	A. S. 11.3	
05	11.5	26	21	
15	21.5	36	30.8	
24.5	31	46.3	40.8	
34.5	41	56	50.8	at 10^h 54^m arc { 0°.19
10 47 44.8	51.3	10 52 06	10 54 01	0.13
10 46 54.85	10 49 01.35	10 51 16.05	10 53 10.91	
10 55 16	10 57 10.8			Chronometer comparisons
26	20.7		Pock. Chron'r	P. M.
35.7	30.6			11^h 56^m 01^s.5 = 3^h 57^m by 2007
45.8	40.4		Deduced hourly rate (between 6^h and 12^h) = $+^s$.14	56 40.9 55 1062
56	50.6			58 17.3 57 740
H. R. 06	H R. 00.6			
16	10.6			
25.9	20.6			
35.8	30.3			
45.9	40.2			at 11^h 0^m temp. { 24°.5
10 56 56	10 58 50.3			bar. 29^{in}.700 at 27°.8 23.5
10 56 05.92	10 58 00.52			

Experiments, set 3, face 1. September 27 A. M.

L.	R.	L.	R.	
10 18 48	10 21 12.8	10 24 41	10 26 46	at $10^h\ 18^m$ arc $\begin{cases} 2^\circ.05 \\ 1.97 \end{cases}$
58.3	22.8	51.2	56	temp. $\begin{cases} 16^\circ.0 \\ 17.8 \end{cases}$
08	32.5	01.5	06	
18	42.5	11.3	16	bar. $29^{in}.752$ at $21^\circ.5$
28	52.8	21	26	
A. S. 38.5	A. S. 03	A. S. 31.3	A. S. 36	
48	12.8	41	45.8	
57.8	22.5	51	56	
08	32.5	01.3	06	
18	42	11	16	at $10^h\ 29^m$ arc $\begin{cases} 1^\circ.72 \\ 1.60 \end{cases}$
10 20 27.8	10 22 52.5	10 26 21	10 28 26	
10 19 38.04	10 22 02.61	10 25 31.15	10 27 35.98	
10 31 56.7	10 34 39.3	10 37 16.2	10 39 48.5	at $10^h\ 42^m$ arc $\begin{cases} 1^\circ.40 \\ 1.32 \end{cases}$
06.8	49.3	26	58.4	
16.8	59.1	35.9	08.7	
26.8	09.4	45.8	18.7	
36.7	19.2	56	28.5	
H. R. 46.5	H. R. 29.2	H. R 06	H R. 38.7	
56.6	39.3	16	48.6	
06.8	49.2	25.8	58.6	
17.0	59.2	35.7	08.5	
27.0	09.1	45.8	18.5	
10 33 37.0	10 36 19.0	10 38 55.8	10 41 28.5	
10 32 46.79	10 35 29.21	10 38 05.91	10 40 38.56	
10 43 33	10 45 32	2 37 15.3	2 39 11.8	at $2^h\ 38^m$ arc $\begin{cases} 0^\circ.16 \\ 0.10 \end{cases}$
43	41.8	25	21.5	temp. $\begin{cases} 23^\circ.2 \\ 21.0 \end{cases}$
53	51.8	35	31.5	
03.2	02	45	41.5	bar. $29^{in}.726$ at $24^\circ.0$
13	12	55	51.8	
A. S. 23	A. S. 21.8	A. S. 05	A. S. 01.8	
32.8	31.5	15	11.5	
43	41.8	25	21.8	
53	51.8	35	31.5	
03	02	45	41.5	at $2^h\ 46^m$ arc $\begin{cases} 0^\circ.14 \\ 0.09 \end{cases}$
10 45 12.8	10 47 12	2 38 55	2 40 51.3	
10 44 22.98	10 46 21.86	2 38 05.03	2 40 01.59	
2 41 30.5	2 43 31.2	2 46 20	2 48 16.7	
40.8	41	29.9	26.7	
50.5	51	40	36.8	
00.5	01	49.8	46.8	
10.5	11	00.1	56.5	
A S. 20.5	A. S. 21	H. R. 10	H. R. 06.7	
30.5	31	20.2	16.6	
40.5	41	30	26.6	
50.5	51	40	36.6	
00.5	00.8	49.7	46.4	
2 43 10.3	2 45 11	2 48 00	2 49 56.6	
2 42 20.51	2 44 21.00	2 47 09.97	2 49 06.64	

L.	R.	L.	R.	
2 50 23.7	2 52 24			Chronometer comparisons
33.5	34.2			A. M.
43.3	44	.	Pock. Chron'r	$9^h\ 34^m\ 03^s.7 = 1^h\ 35^m$ by 2007
53.5	53.8			35 42.8 34 1062
03.6	3.7			36 19.7 35 740
H. R. 13.6	H. R. 13.9			P. M.
23.3	23.8		Deduced hourly rate (between 9^h and 3^h) $= +^s.02$	3 41 04.5 7 42 2007
33.5	33.9	.		42 42.7 41 1062
43.3	43.8			46 19.8 45 740
53.3	53.8			
2 52 03.4	2 54 04.0			
2 51 13.45	2 53 13.90			

Experiments, Set 4, face 3. September 28.

L.	R.	L.	R.	
0 50 53.5	0 52 48	0 55 01	0 56 53.8	at $0^h\ 50^m$ arc $\begin{cases}1^\circ.56\\ 1.38\end{cases}$
03.5	58	11	03.8	at 0 40
13.3	08.5	21	13.8	temp. $\begin{cases}20^\circ.2\\ 21.0\end{cases}$
23.3	18	31	23.5	bar. $29^{in}.536$ at $27^\circ.5$
33	28	41	33.5	The time was noted when the
A. S. 43.3	A. S. 38	A. S. 51	A. S. 43.5	knife-edge passed a mark $0^\circ.1$
53.2	48	01	53.5	to the left (in inverting tele-
03.5	58	11	03.5	scope) from the zero line. The
13.2	08.2	20.8	13.5	elongations were equal on
23	18	30.8	23.3	either side of this mark.
0 52 33	0 54 28	0 56 40.8	0 58 33.3	
0 51 43.25	0 53 38.06	0 55 50.95	0 57 43.55	at $0^h\ 59^m$ arc $\begin{cases}1^\circ.42\\ 1.22\end{cases}$
1 00 28.3	1 02 23	1 04 18	1 06 22.7	
38.3	33.2	28	32.5	at $1^h\ 08\frac{1}{2}^m$ arc $\begin{cases}1^\circ.23\\ 1.03\end{cases}$
48.3	43.1	37.8	42.6	
58.3	53.2	47.8	52.6	
08.3	03.2	57.9	02.8	
H. R. 18.2	H. R. 13.2	H. R. 08	H. R. 12.7	
28.2	23.2	17.9	22.6	
38.1	33	27.8	32.5	
48.2	43	37.9	42.4	
58.2	52.9	47.7	52.5	
1 02 08.3	1 04 03.2	1 05 57.9	1 08 02.6	
1 01 18.24	1 03 13.11	1 05 07.88	1 07 12.59	
1 10 17.3	1 12 10.3	1 36 58	1 38 52.5	at $1^h\ 42^m$ temp. $\begin{cases}25^\circ.7\\ 24.0\end{cases}$
27.3	20	08	02.8	
37	29.8	18	12.8	
47	39.8	28	22.5	
57	49.8	38.2	32.5	
A. S. 07.2	A. S. 00	A. S. 48	A. S. 42.5	
17	10	58	52.5	
27	20	08	02.8	
37	29.8	18	12.8	
47	39.8	27.8	22.5	
1 11 57	1 13 49.5	1 38 37.8	1 40 32.5	
1 11 07.07	1 12 59.89	1 37 47.98	1 39 42.61	

L.	R.	L.	R.	
2 43 50.5	2 45 57	5 00 32.3	5 02 25	at $2^h\ 50^m$ temp. { 26°.7 / 24.3 }
00.3	07	42	35	
10.2	17	52	45	
20.3	27	02.5	55	bar. $29^{in}.516$ at 29°.3
30	37	12	05	
A. S. 40	A. S. 46.8	A. S. 22	A. S. 15	
50	56.8	32.3	25	
00	06.8	42.2	34.8	
10.5	16.5	52	45	at $5^h\ 0^m$ arc { 0°.22 / 0.02 }
20	26.5	02.5	55	
2 45 30	2 47 36.5	5 02 12.3	5 04 05	temp. { 26.°5 / 24.3 }
2 44 40.16	2 46 46.81	5 01 22.19	5 03 14.98	bar. $29^{in}.508$ at 32°.5
5 04 32	5 06 26.8	5 09 21.3	5 11 19.9	
42	36.8	31.4	30.	
52	46.8	41.3	39.8	
02	56.8	51.3	50	
12	06.8	01.7	00.2	
A. S. 21.8	16.5	H. R. 11.2	H. R. 10.2	
31.5	26.5	21.3	20.1	
41.8	36.5	31.2	30.2	
51.3	46.5	41.3	40.2	
02	56.5	51.3	50.2	
5 06 12	5 08 06.5	5 11 01.3	5 13 00 1	
5 05 21.87	5 07 16.64	5 10 11.33	5 12 10.08	
5 13 39	5 15 35.3			Chronometer comparisons
48.7	45.3			
58.7	55.6		Pock. Chron'r	$0^h\ 4^m\ 8^s.3 = 4^h\ 5^m$ by 2007
08.9	05.4		Deduced hourly rate (between 0^h and 5^h) $= +^s.05$	4 45.2 = 3 by 1062
18.8	15.5			5 22.7 = 4 by 740
H. R. 28.5	H. R. 25.3			
38.6	35.6			4 39 8.8 = 8 40 by 2007
48.6	45.3			40 45.2 = 39 by 1062
58.7	55.3			41 22.3 = 40 by 740
08.8	05.4			
5 15 18.8	5 17 15.5			
5 14 28.74	5 16 25.41			

Experiments, set 5, face 3. September 29.

L.	R.	L.	R.	
0 45 43.5	0 47 32.8	0 49 25.3	0 51 24	at $0^h\ 44\frac{1}{2}^m$ arc { 1°.96 / 1.76 }
53.8	42.5	35.3	34	
03.8	52.5	45.3	44	temp. { 14°.8 / 15.8 }
13.8	02.8	55.3	54	
23.5	12.8	05.3	04	bar. $29^{in}.596$ at 14°.2
A. S. 33.5	A. S. 22.5	A. S. 15.3	A. S. 14	
43.5	32.5	25.5	24	
53.5	42.3	35	34	
3.5	52.5	45.3	44	
13.5	02.5	55.3	54	at $0^h\ 53\frac{1}{2}^m$ arc { 1°.73 / 1.55 }
0 47 23.5	0 49 12.5	0 51 05.5	0 53 04	
0 46 33.58	3 48 22.56	0 50 15.31	0 52 14.03	

L.	R.	L.	R.	
0 54 05.2	0 56 21.7	0 58 28.4	1 01 21.1	at $1^h\ 02\frac{1}{2}^m$ arc $\begin{cases}1^\circ.52\\1.28\end{cases}$
15.2	31.6	38.2	31.1	
25.2	41.4	48.2	40.9	
34.9	51.4	58.2	51	
44.8	01.4	08.4	01.2	
H. R. 54.8	H. R. 11.7	H. R. 18.2	H. R. 11.2	
04.9	21.5	28.2	21.1	
14.8	31.4	38.2	31	
24.8	41.4	48.2	40.8	
34.6	51.4	58.2	50.8	
0 55 44.8	0 58 01.5	1 00 08.3	1 02 01.0	
0 54 54.91	0 57 11.49	0 59 18.25	1 01 11.02	
1 03 23.5	1 05 16.5	4 51 19	4 53 25.5	at $4^h\ 51^m$ arc $\begin{cases}0^\circ.21\\0.02\end{cases}$
33.5	26.5	28.8	35.5	
43.5	36.5	38.8	45.5	at $4^h\ 50^m$ temp. $\begin{cases}14^\circ.5\\16.6\end{cases}$
53.5	46.5	48.8	55.5	
04	56.5	58.5	5.5	
A. S. 13.5	A. S. 06.5	A. S. 08.5	15.5	bar. $29^{in}.658$ at $20^\circ.0$
23.5	16.5	18.5	25.5	
33.5	26.5	28.5	35	
43.3	36.5	38.5	45.3	
53.5	46.5	48.5	55.5	
1 05 03.5	1 06 56.2	4 52 58.8	4 55 05.5	
1 04 13.53	1 06 06.47	4 52 08.65	4 54 15.44	
4 55 24	4 57 17	4 59 39.7	5 01 40.4	at $4^h\ 59^m$ arc $\begin{cases}0^\circ.21\\0.01\end{cases}$
34	27	49.6	50.4	
44	37	59.8	00.6	
54	47	09.9	10.7	
04.3	57	19.9	20.6	
A. S. 14	A. S. 07	H. R. 30	H. R. 30.6	
24	17	39.6	40.3	
34	27	49.6	50.4	
44	37	59.8	00.4	
54	46.8	09.8	10.4	
4 57 04.5	4 58 57	5 01 19.8	5 3 20.4	
4 56 14.07	4 58 06.98	5 00 29.77	5 02 30.47	
5 03 33.3	5 05 24	During the last sets of observations a very heavy gale shook the skins with which the observatory is lined, but it appeared not to affect the motion of the pendulum.		Chronometer comparisons
43.2	34			Pock. Chron'r
53.4	43.8			$0^h\ 08^m\ 12^s.0 = 4^h\ 9^m$ by 2007
03.3	53.8			8 47.1 7 1062
13.2	04.1			9 24.0 8 740
H. R. 23.2	H. R. 14			
33.2	24.2			4 31 13.2 8 32 2007
43.2	34			32 47.8 1062
53.2	43.8			33 25.2 740
03.3	53.8			Deduced hourly rate (between
5 05 13.2	5 07 04.0			0^h and 4^h) = $-^s.17$
5 04 23.25	5 06 13.95			

Experiments, set 6, face 3, October 2.

L.			R.			L.			R.			
10	12	32	10	14	32	10	16	25.5	10	18	20.8	at $10^h\ 11^m$ arc $\{1^\circ.95$
		42			33			35.8			30.5	1.75
		52			43			45.5			40.5	
		02			53			56			50.5	at $10^h\ 0^m$ $\{15^\circ.0$
		12			03			06			00.5	temp.
A. S.		22	A. S.		13	A. S.		15.8	A. S.		10.5	bar. $29^{in}.762$ at $22^\circ.0$ 16.0
		32			23			25.5			20.5	
		42.3			33			35.5			30.5	
		52			43			45.5			40.5	
		02			53			55.5			50.5	at $10^h\ 20\frac{1}{2}^m$ arc $\{1^\circ.69$
10	14	12	10	16	03	10	18	05.5	10	20	00.5	1.49
10	13	22.03	10	15	13.00	10	17	15.65	10	19	10.53	
10	22	13.2	10	24	45.8	10	26	50.6	10	28	47.3	at $10^h\ 31^m$ arc $\{1^\circ.47$
		23.2			55.8			00.7			57.4	1.25
		33.1			06			10.8			07.7	
		43			16			20.7			17.5	
		53.2			25.9			30.7			27.4	
H. R.		3.2	H. R.		35.8	H. R.		40.6	H. R.		37.4	
		13.2			45.8			50.6			47.4	
		23.2			55.7			00.7			57.5	
		33			05.9			10.7			07.5	
		43.2			16			20.7			17.5	
10	23	53.2	10	26	25.7	10	28	30.6	10	30	27.3	
10	23	03.15	10	25	35.85	10	27	40.67	10	29	37.45	
10	31	54	10	34	07	2	15	46.5	2	17	47.0	at $2^h\ 15^m$ arc $\{0^\circ.23$
		04			17			56 5			57.3	temp. $\{23^\circ.2$ 0.03
		14			26.8			06.8			07.3	21.0
		24			37			16.5			17.5	bar. $29^{in}.828$ at $30^\circ.5$
		34			46.8			26.5			27.5	
A. S.		44	A. S.		56.5	A. S.		36.5	A. S.		37.5	
		54			06.5			46.5			47.3	
		04			16.8			56.5			57.5	
		14			26.8			06.8			07.3	
		24			36.5			16.5			17.3	
10	33	34	10	35	46.5	2	17	26.5	2	19	27.3	
10	32	45.00	10	34	56.75	2	16	36.55	2	18	37.35	
2	19	46	2	21	38.8	2	24	15.7	2	26	10.5	
		56			48.8			25.6			20.4	
		06.3			59			35.4			30.4	
		16.3			09			45.3			40.3	
		26.1			18.8			55.4			50.2	
A. S.		36	A. S.		28.8	H. R.		05.6	H. R.		00.2	
		46			38.8			15.6			10.4	
		56			48.5			25.5			20.3	
		06			58.8			35.2			30.2	
		16.3			08.8			45.4			40.2	
2	21	26	2	23	18.8	2	25	55.4	2	27	50.1	
2	20	36.09	2	22	28.81	2	25	05.46	2	27	00.29	

L.	R.			
2 27 59.2	2 29 51.8			at 2^h 30^m arc $\begin{cases}0°.21\\0.01\end{cases}$
09.3	01.8			
19.1	11.8			Comparison of chronometers
29	21.8	Pock. chronom'r		9^h 32^m $25^s.7 = 1^h$ 33^m by 2007
39.1	31.7			33 55.5 32 1062
H. R. 49.1	H. R. 41.7			35 32.8 34 740
59.1	51.7			
09.1	01.8	N. B. Of this set no use has been made.		The chronometer changed its correction 2^m 10^s between 9 A.M. and 3 P. M. (October 2). For later comparisons see further on.
19	11.8			
29	21.7			
2 29 39	2 31 31.7			
2 28 49.09	2 30 41.75			
Experiments, set 7, face 3. October 2.				
2 46 49.5	2 48 42	2 50 39	2 52 37.5	at 2^h 46^m arc $\begin{cases}1°.83\\1.62\end{cases}$
59.8	52.3	49	47.5	
09.5	02	59	57.8	
19.5	12.3	09.3	07.8	
29.5	22	19	17.8	
A. S. 39.5	A. S. 32	A. S. 29	A. S. 27.8	
49.5	42	39	37.8	
59.5	52	49	47.8	
09.5	02	59	57.8	
19.3	12	09	07 8	at 2^h $54\frac{1}{2}^m$ arc $\begin{cases}1°.55\\1.37\end{cases}$
2 48 29	2 50 22	2 52 19	2 54 17.8	
2 47 39.46	2 49 32.05	2 51 29.03	2 53 27.75	
2 55 32.3	2 57 23 1	2 59 16	3 01 04.8	at 3^h 4^m arc $\begin{cases}1°.43\\1.21\end{cases}$
42.2	33.1	26	14.8	
52.2	43.1	35.8	24.7	at 3^h 5^m
02.4	53.1	45.7	34.6	temp. $\begin{cases}27°.0\\24.5\end{cases}$
12.4	03.2	55.8	44.5	
H. R. 22.2	H. R. 13.2	H. R. 05.9	H. R. 54.5	
32.2	23	16	04.7	
42.1	33	25.8	14.6	
52.1	43	35.8	24.5	
02.2	53	45.7	34.4	
2 57 12.3	2 59 03.1	3 0 55.8	3 02 44.5	
2 56 22.24	2 58 13.08	3 0 05.85	3 01 54.60	
(7 8 10)	7 10 12.5	7 12 19	7 14 16	at 7^h 7^m arc $\begin{cases}0°.21\\0.01\end{cases}$
20	22.5	29	26	
30	32	38.8	35.5	at 7^h 5^m
39.8	42	49	46	temp. $\begin{cases}27°.0\\23.0\end{cases}$
49.8	52	59	56	bar. $29^{in}.840$ at 26°.0
A. S. 59.5	A. S. 02.3	A. S. 09	A. S. 06	
09.8	12.5	19	16.5	
20	22.3	29	25.5	
29.5	32.3	39	35.5	
39.5	42.3	48.8	45.5	
- - - - - -	7 11 52.3	7 13 59	7 15 55.5	
7 08 59.79	7 11 02.27	7 13 08.96	7 15 05.77	

L.	R.	L.	R.	
(7 16 54.5)	7 19 19.2	7 21 21.9	7 23 16.8	Chronometer comparisons
04.8	29.2	32	26.6	Pock. chronom'r
14.8	39.3	42	36.7	3^h 17^m $14^s.7$ = 7^h 20^m by 2007
24.8	49.2	52	46.6	17 43.6 18 1062
34.5	59.2	02.2	56.7	19 21.0 20 740
A. S. 44.4	A. S. 09.2	A. S. 12.2	A. S. 06.8	6 45 15.0 10 48 2007
54.3	19.2	21.9	16.7	46 43.3 47 1062
—[1]	29.2	32.1	26.7	48 21.0 49 740
14.5	39.2	42.1	36.8	[1] 4.4 interpolated
24.5	49.1	51.8	46.5	Deduced hourly rate (between
—	7 20 59.1	7 23 02.0	7 24 56.6	3^h and 7^h) = $+^s.05$
7 17 44.45	7 20 09.19	7 22 12.02	7 24 06.68	
Experiments, set 8, face 4. October 3.				
11 02 02	11 03 58.8	11 05 49.5	11 07 40.5	at 11^h $1\frac{1}{2}^m$ arc { 1°.97
12.3	08.8	59.5	50.5	1.88
22.3	18.8	09.5	00.5	at 11^h 0^m temp. { 18°.2
32	29	19.5	10.5	18.0
42.3	39	29.5	20.5	bar. $29^{in}.810$ at 24.5
A. S. 52	A. S. 49	A. S. 39.5	A. S. 30.5	
02	58.8	49.8	40.5	The time was noted when the
12	09	59.5	50.5	knife-edge No. 4 passed over
22	19	09.5	00.5	a mark 0°.05 to the left (in
32	29	19.5	10.5	inverting telescope) of the zero
11 03 42	11 05 39	11 07 29.5	11 09 20.5	of the arc.
11 02 52.08	11 04 48.93	11 06 39.53	11 08 30.50	
11 11 31.2	11 13 26.0	11 15 16.9	11 17 05.8	at 11^h 10^m arc { 1°.70
40.9	35.9	26.9	15.7	1.60
51	45.8	36.6	25.5	The pendulum gained 6.85 vibra-
01.2	55.8	46.5	35.4	tions in an hour on the pocket
11.2	06	56.7	45.3	chronometer.
H. R. 21.1	H. R. 16.1	H. R. 06.8	H. R. 55.4	
31	26.2	16.8	05.6	
41	35.8	26.6	15.6	
51.1	45.7	36.5	25.5	at 11^h 20^m arc { 1°.47
1.2	55.8	46.5	35.4	1.38
11 13 11.2	11 15 05.9	11 16 56.6	11 18 45.3	
11 12 21.10	11 14 15.91	11 16 06.67	11 17 55.50	
11 20 46	11 22 39	11 52 56.8	11 54 51.3	
56.3	49	06.8	01.5	
06.3	59	16.8	11.5	
16.3	09	26.5	21.3	
26	19	36.5	31.3	
A. S. 36	A. S. 28.8	A. S. 46.5	A. S. 41	
46	38.8	56.5	51.2	
56	49	06.5	01.2	
06	59	16.5	11.2	
16	09	26.5	21	
11 22 25.8	11 24 18.8	11 54 36.5	11 55 31	
11 21 36.06	11 23 28.95	11 53 46.58	11 55 41.23	

L.	R.	L.	R.	
0 47 06.5	0 48 57	2 59 59	3 01 53.5	at $3^h\ 1^m$ arc $\{$ 0°.19
16.3	07	09.3	03 8	at $3^h\ 0^m$ $\{$ 0.08
26.5	17	19	13.8	temp. $\{$ 20°.5
36.2	27	29	23.5	20.0
46.2	37	39	33.2	bar. $29^{in}.774$ at 27°.0
A. S. 56.2	A. S. 47	A. S. 49	A. S. 43.5	
06.2	57	59	53.5	
16	07.2	09	03.8	
26.2	17	19	13.8	
36	27	29	23.5	
0 48 46	0 50 37	3 1 39	3 3 33.5	
0 47 56.21	0 49 47.02	3 0 49.03	3 02 43.58	
3 03 44	3 05 35	3 08 20.3	3 10 09.1	
54.3	45.2	30.2	19.1	
04.5	55.3	40.1	29	
14.5	05.5	50.1	39	
24.5	15.5	00.2	49	
A. S. 34.3	A. S. 25.3	H. R. 10.2	H. R. 59	
44.5	35	20.2	09	
54.3	45.2	30.2	19	
04.5	55	40.1	28.8	
14.5	05.3	50.1	38.7	
3 05 24.5	3 07 15.2	3 10 00.1	3 11 48.6	
3 04 34.40	3 06 25.23	3 09 10.16	3 10 58.94	Chronometer comparisons Pock. chron'r
3 12 02	3 14 18.3		Deduced hourly rate (between 10^h and 4^h) = $+^s.06$	$10^h\ 08^m\ 16^s.8 = 2^h\ 11^m$ by 2007
11.9	28.3			09 43.7 10 1062
21.8	38.3			10 21.7 11 740
31.7	48.3			
41.5	58.3			1 04 17.0 5 7 2007
H. R. 51.5	H. R. 08.6			04 43.8 5 1062
01.7	18.4			05 21.2 6 740
11.7	28.4			
21.5	38.4			4 37 17.1 8 40 2007
31.4	48.2			38 43.7 39 1062
3 13 41.5	3 15 58.2			39 21.3 40 740
3 12 51.65	3 15 08.34			

Experiments, set 9, face 4. October 4.

11 20 44.8	11 22 38	11 24 34.8	11 26 25.5	at $11^h\ 20^m$ arc $\{$ 1.°77
54.8	48	44.8	35.3	1.63
05.2	57.8	54.5	45	at $11^h\ 15^m$ temp. $\{$ 23°.0
15	08	04.5	55.3	23.7
25	18	14.5	05.5	bar. $29^{in}.966$ at 30°.0
A. S. 35	A. S. 28	A. S. 24.5	A. S. 15.5	
44.8	38	34.5	25 3	
54.8	48	44.5	35.3	
04.8	57.8	54.5	45.2	
14.8	07.8	04.5	55.2	at $11^h\ 28\frac{1}{2}^m$ arc $\{$ 1°.5
11 22 24.8	11 24 18	11 26 14.5	11 28 05.5	1.43
11 21 34.89	11 23 27.95	11 25 24.55	11 27 15.33	

L.	R.	L.	R.	
11 29 36.2	11 31 39	11 33 25.8	11 35 20.3	
46.1	49	35.6	30.5	
56.1	59	45.6	40.5	
06.3	09	55.5	50.4	
16.3	19	05.7	00.4	
H. R. 26.2	H. R. 29.1	H. R. 15.8	H. R. 10.5	
36.2	38.9	25.7	20.5	
46.2	48.8	35.6	30.5	
56.1	58.8	45.4	40.4	
06.2	08.9	55.4	50.3	
11 31 16.2	11 33 18.8	11 35 05.7	11 37 00.4	
11 30 26.19	11 32 28.94	11 34 15.62	11 36 10.43	
3 55 29	3 57 29.8	3 59 26.3	4 01 19.5	at 3^h 55^m arc { $0^\circ.14$
39	39.5	36.3	29.3	0.04
49	49.5	46.5	39.3	at 4^h 0^m temp. { $26^\circ.0$
59	59.8	56.5	49.2	bar. $30^{in}.010$ at $33^\circ.0$ { 25.0
09.3	09.8	06.5	59.5	
A. S. 19	A. S. 19.5	A. S. 16.6	A. S. 09.3	
29	29.6	26.5	19.3	
39	39.5	36.5	29.3	
49	49.5	46.5	39.3	
59	00	56.5	49.3	
3 57 09	3 59 9.8	4 01 06.5	4 02 59.5	
3 56 19 03	3 58 19.66	4 00 16.47	4 02 09.35	Chronometer comparisons
4 05 22	4 07 16.9	4 09 09.7	4 11 04.4	Pock. Chron'r
31.9	26.8	19.7	14.5	10^h 25^m $18^s.8$ = 2^h 28^m by 2007
41.7	36.6	29.6	24.3	26 44.0 27 1062
52	46.5	39.3	34.2	27 22.0 28 740
02	56.7	49.2	44.2	
H. R. 12	H. R. 06.8	H. R. 59.6	H. R. 54.2	4 51 21.1 8 54 2007
22	16.7	09.5	04.3	52 45.4 53 1062
31.8	26.7	19.6	14.3	53 23.5 54 740
41.7	36.5	29.5	24.2	Deduced hourly rate (between
51.8	46.4	39.2	34.2	10^h and 5^h) = — ^{s}.21
4 07 01.8	4 8 56.4	4 10 49.2	4 12 44	
4 06 11.88	4 08 16.64	4 09 59.46	4 11 54.25	
Experiments, set 10, face 2. October 5.				
10 56 10.3	10 58 05	11 00 03.8	11 01 56.5	at 10^h $55\frac{3}{4}^m$ arc { $1^\circ.92$
20	15	13.5	06.5	1.76
30	25	23.5	16.5	at 10^h 30^m temp. { $24^\circ.8$
40	34.8	33.5	26.3	24.2
50	44.8	43.5	36.3	bar. $29^{in}.970$ at 270
A. S. 00	A. S. 54.8	A. S. 53.5	A. S. 46.3	
10	05	03.5	56.3	
20	15	13.5	06.5	
30	24.5	23.3	16.5	
40	34.8	33.3	26.3	at 11^h 4^m arc { $1^\circ.68$
10 57 50	10 59 44.5	11 01 43.3	11 03 36.3	1.52
10 57 00.03	10 58 54.84	11 00 53.47	11 02 46.39	

L.	R.	L.	R.	
11 05 34.8	11 07 32	11 09 28.5	11 11 19.4	at 11^h 14^m arc 1°.48
45	41.7	38.3	29.6	1.32
55.1	51.8	48.4	39.3	
05.2	01.8	58.5	49.3	
15.2	12	08.7	59.5	
H. R. 25.2	H. R. 21.8	H. R. 18.6	H. R. 09.6	
35	31.6	28.5	19.4	
45	41.7	38.5	29.4	
54.8	51.7	48.4	39.2	
05.1	01.7	58.5	49.2	
11 07 15	11 09 11.7	11 11 08.4	11 12 59.3	
11 06 25.04	11 08 21.77	11 10 18.48	11 12 09.39	
11 14 12	11 16 07	11 55 37.5	11 57 40	
22	17.2	47.8	50.2	
32	27	57.5	00.2	The pendulum gained $6^s.62$ on
42	37	07.5	10.3	the chronometer in one hour.
52	47	17.3	20.3	
A. S. 02.2	A. S. 57	A. S. 27.3	A. S. 30.3	
12	07	37.3	40	
22	17	47.3	50	
32	26.7	57.5	00.2	
42	36.8	07.3	10.2	
11 15 52	11 17 46.8	11 57 17.3	11 59 20.3	
11 15 02.02	11 16 56.95	11 56 27.42	11 58 30.18	
0 49 58	0 51 58.5	3 43 50	3 45 53	at 1^h 0^m temp. 29°.0
08.3	08.5	00.2	03	bar. $29^{in}.950$ at 31°.5 26.8
18	18.5	10.3	13	
28	28.5	20.3	22.8	
37.8	38.3	30	32.8	
A. S. 48	A. S. 48.5	A. S. 40	A. S. 42.8	
58	58.5	50	52.8	
07.8	08.5	00.2	02.5	at 3^h 43^m arc 0°.22
18	18.8	10.3	12.8	— 0.03
27.8	28.8	20.2	22.5	at 3^h 40^m temp. 30°.0
0 51 37.5	0 53 38.5	3 45 29.8	3 47 32.5	bar. $29^{in}.908$ at 30°.0 27.0
0 50 47.93	0 52 48.54	3 44 40.12	3 46 42.77	
3 47 43.5	3 49 36.2	3 52 31.1	3 54 39.8	
53.6	46.2	41.2	49.8	
03.5	56.3	51.2	00	
13.5	06.5	01.4	10.1	
23.5	16.8	11.3	20.1	
A. S. 33.2	A. S. 26.2	H. R. 21.3	H. R. 29.8	
43.2	36.2	31	39.8	
53.5	46.2	41	49.8	
03.6	56.3	51.2	00	
13.5	06.5	01.4	10.2	
3 49 23.5	3 51 16.3	3 54 11.2	3 56 19.9	
3 48 33.46	3 50 26.34	3 53 21.21	3 55 29.94	

L.	R.	L.	R.	
3 56 34.5	3 58 31.5			Comparison of chronometers
44.6	41.4		Pock. Chron'r	$9^h\ 57^m\ 22^s.8 = 2^h\ 0^m$ by 2007
54.8	51.5			57 46.0 1 58 1062
04.8	01.8			59 24.3 2 0 740
14.8	11.7			
H. R. 24.6	21.4			4 33 23.5 8 36 2007
34.5	31.2			34 45.9 35 1062
44.6	41.3			36 24.2 37 740
54.7	51.2			
04.8	01.3			Deduced hourly rate (between
3 58 14.7	4 00 11.5			10^h and 4^h) = + $^s.03$
3 57 24.67	3 59 21.44			

Experiments, set 11, face 2. October 6.

10 51 19.5	10 53 14.2	10 55 11.2	10 57 12	at $10^h\ 48^m$ arc { 1°.83
29.5	24	21	22	1.62
39	34	31	31.5	at $10^h\ 35^m$ temp. { 20°.8
49.3	43.8	40.8	41.5	22.0
59.5	54.2	50.8	51.5	bar. $29^{in}.760$ at 25°.0
A. S. 09.5	A. S. 04.3	A. S. 01	A. S. 02	
19.5	14.3	11	12	
29.3	24	21	21.5	
39	34	30.5	31.5	
49	44	40.5	41.5	at $10^h\ 59^m$ arc { 1°.56
10 52 59.2	10 54 54.2	10 56 50.5	10 58 51.5	1.32
10 52 09.30	10 54 04.09	10 56 00.85	10 58 01.68	
11 03 16.5	11 05 11.2	11 07 26	11 09 20.4	at $11^h\ 12^m$ arc { 1°.34
26.3	21.2	35.6	30.5	1.12
36.2	31.2	45.6	40.5	at $11^h\ 45^m$ temp. { 24°.7 ?
46.2	41.1	55.6	50.6	bar. $29^{in}.788$ at 33° 27.0
56.3	51	05.7	00.5	
H. R. 06.3	H. R. 01	H. R. 15.7	H. R. 10.5	
16.3	11.1	25.7	20.4	
26.2	21.1	35.5	30.4	
36.2	31	45.4	40.4	
46	41	55.5	50.3	
11 04 56.2	11 06 51	11 09 05.6	11 11 00.4	
11 04 06.25	11 06 01.08	11 08 15.63	11 10 10.45	
11 49 09	11 51 04	3 18 04	3 19 56.5	at $3^h\ 18^m$ arc { 0°.22
19	13.8	14	06.6	—0.02
29	23.5	24	16.5	at $3^h\ 20^m$ temp. { 27°.8
38.8	33.5	34	26.7	bar. $29^{in}.772$ at 33°.0 24.2
49	43.5	44	36.5	
A. S. 59	A. S. 53.8	A. S. 54	A. S. 46.5	
09	03.8	04	56.5	
19	13.8	14	06.5	
29	23.5	23.8	16.5	
39	33.5	33.8	26.5	
11 50 48.8	11 52 43.3	3 19 43.8	3 21 36.5	
11 49 58.96	11 51 53.64	3 18 53.95	3 20 46.53	

L.	R.	L.	R.	
3 21 49.5 59.5 09.8 19.5 29.6 A. S. 39.5 49.5 59.5 09.5 19.5 3 23 29.5	3 23 42 52.3 02.3 12.3 22.3 A. S. 32.2 42.3 52.2 02.3 12.2 3 25 22	3 27 34.8 45 55 05 15 A. S. 24.9 34.8 44.7 54.8 04.8 3 29 14.8	3 29 31.6 41.6 51.6 01.6 11.7 A. S. 21.4 31.4 41.4 51.5 01.5 3 31 11.5	
3 22 39.54	3 24 32.21	3 28 24.87	3 30 21.53	
3 31 20.3 30.3 40.3 50.3 00.3 H. R. 10.3 20.3 30.2 40.2 50.2 3 33 00.2	3 33 13.2 23.2 33 43 53.1 H. R. 03.2 13.2 23 33 43 3 34 53.1			Chronometer comparisons Pock. Chronom'r 10^h 08^m $25^s.1 = 2^h$ 11^m by 2007 09 46.2 10 1062 10 24.9 11 740 4 45 25.9 8 48 2007 46 46.4 47 1062 47 25.2 48 740 Deduced hourly rate (between 10^h and 4^h) = — $0^s.01$
3 32 10.26	3 34 13.09			
Experiments, set 12, face 2. October 8.				
10 50 11.3 21.2 31.2 41 51 A. S. 01 11.2 21 31 41 10 51 51	10 52 00 10.2 20 30 40 A. S. 50 00 10 20 30 10 53 39.8	10 54 01 11 21 30 8 40.7 A. S. 50.5 00.8 10.8 20.5 30.6 10 55 40.5	10 56 25.8 35.5 45.3 55.5 05.5 A. S. 15.5 25.5 35.5 45.3 55.3 10 58 05.5	at 10^h $49^m.5$ arc $\begin{cases}1^\circ.97\\ 1.75\end{cases}$ at 10^h 35^m temp. $\begin{cases}25^\circ.8\\ 25.0\end{cases}$ bar. $30^{in}.064$ at $26^\circ.8$ at 10^h $58^m.5$ arc $\begin{cases}1^\circ.74\\ 1.52\end{cases}$
10 51 01.08	10 52 50.00	10 54 50.75	10 57 15.47	
10 59 22.3 32.2 42.2 52.2 02.2 H. R. 12.2 22.2 32.2 42 52 11 01 02.1	11 01 21 31 41 50.9 01 H. R. 11 21 30.7 40.8 50.7 11 03 00.9	11 03 11.9 21.6 31.8 41.8 51.6 H. R. 01.8 11.8 21.7 31.6 41.7 11 04 51.5	11 05 12.6 22.6 32.5 42.5 52.4 H. R. 02.5 12.6 22.4 32.4 42.3 11 06 52.2	
11 00 12.16	11 02 00.91	11 04 01.71	11 06 02.45	

L.	R.	L.	R.	
2 58 25.8	3 00 20.5	3 02 13	3 04 04	at $3^h\ 6^m$ arc { 0°.22
35.5	30.5	23	14	0.02
45.5	40.2	33	23.8	temp. { 26°.3 bar. $30^{in}.012$ at 34.0
55.5	50.3	43	33.8	28.5
05.5	00.5	53	43.5	
A. S. 15.5	A. S. 10.5	A. S. 03.2	A. S. 54	
25.5	20.2	13	04	
35.5	30.2	23	14	
45.5	40.1	32.8	23.5	
55.5	50.2	43	33.8	
3 00 05.5	3 02 00.3	3 03 53	3 05 43.8	
2 59 15.53	3 01 10.32	3 03 03.00	3 04 53.84	
3 06 32.7	(3 08 25.5)	3 10 06.3	3 11 55.2	During these observations the
42.6	35.3	16.3	05.2	wind was strong from the south,
52.6	45.3	26.3	15.2	shaking the observatory.
02.7	55.3	36.3	25.2	
12.7	05.5	46.2	35	Chronometer comparisons
H. R. 22.6	H. R. 15.4	H. R. 56.2	45	$10^h\ 09^m\ 0^s.8 = 2^h\ 11^m$ by 2007
32.5	25.3	06.2	55	10 43.3 11 1062
42.4	35.3	16.2	05	11 22.6 12 740
52.3	45.2	26.2	15.1	4 14 00.7 8 16 2007
02.3	55.2	36.3	25.1	14 43.0 15 1062
3 08 12.5	----	3 11 46.1	3 13 35.1	16 22.3 17 740
3 07 22.54	3 09 15.33	3 10 56.24	3 12 45.10	hourly rate (between 10^h and 4^h) $= +0^s.09$
Experiments, set 13, face 2. October 9.				
11 12 55.5	11 14 50	11 16 41	11 18 30	at $11^h\ 12^m$ arc { 1°.87
05.5	00.2	51	40	1.68
15.5	10.3	01	50	at $11^h\ 0^m$ temp. { 25°.8
25.3	20.2	11	00	bar. $30^{in}.126$ at 27°.5 25.6
35.5	30.2	21	10	
A. S. 45.3	A. S. 40.2	A. S. 31	A. S. 20	
55.3	50	40.8	29.8	
05.3	00	51	39.8	
15.5	10.2	01	49.8	
25.3	20	11	59.8	at $11^h\ 20\frac{1}{2}^m$ arc { 1°.62
11 14 35.3	11 16 30.1	11 18 21	11 20 09.5	1.44
11 13 45.39	11 15 40.13	11 17 30.98	11 19 19.88	
11 21 34.4	11 23 21.3	11 25 14.2	11 27 13.1	
44.6	31.2	24	22.8	
54.5	41.2	34	32.8	
04.6	51.2	43.8	42.7	
14.5	01.2	54	52.7	
H. R. 24.4	H. R. 11.2	H. R. 04.1	H. R. 02.8	
34.3	21.1	14.1	12.8	
44.3	31.2	24	22.7	
54.3	41	33.8	32.6	
04.4	51.2	43.7	42.7	
11 23 14.4	11 25 01.2	11 26 53.8	11 28 52.6	
11 22 24.43	11 24 11.18	11 26 03.95	11 28 02.75	

L.	R.	L.	R.	
3 25 19.3	3 27 12	3 29 03	3 30 55.8	at $3^h\ 25^m$ arc { 0°.22
29.5	22	13	05.8	temp. { 29°.5 { 0.02
39.2	32	23	51.5	{ 27.5
49.2	42	32.8	25.5	bar. $30^{in}.070$ at 30°.0
59.3	52	42.5	35.5	
A. S. 09.5	A. S. 02.2	A. S. 52.8	A. S. 45.5	
19.5	12	02.8	55.5	
29.3	22	12.8	05.5	
39.3	32	23.8	15.5	
49	42	32.8	25.5	at $3^h\ 33^m$ arc { 0°.21
3 26 59	3 28 52	3 30 42.5	3 32 35.5	{ 0.01
3 26 09.28	3 28 02.02	3 29 52.80	3 31 45.55	
3 33 32.5	3 35 27.3	3 37 16	3 39 18.9	Chronometer comparisons
42.4	37.2	26.2	28.8	Pock. Chronom'r
52.2	47.2	35.8	38.6	$10^h\ 36^m\ 1^s.2 = 2^h\ 38^m$ by 2007
02.4	57.1	45.7	48.5	37 41.8 38 1062
12.4	07.1	55.8	58.8	38 21.6 39 740
H. R. 22.4	H. R. 17.1	H. R. 05.9	H. R. 08.8	
32.3	27.2	16	18.8	4 07 1.7 8 9 2007
42.3	37	26	28.8	09 41.7 10 1062
52.2	47.2	35.8	38.5	10 21.7 11 740
02.2	57.2	45.6	48.4	Deduced hourly rate (between
3 35 12.2	3 37 07.1	3 38 55.7	3 40 58.5	10^h and 4^h) = + $^s.03$
3 34 22.32	3 36 17.15	3 38 05.86	3 40 08.67	

Experiments, set 14, face 4. October 10.

12 00 52.5	12 02 45	12 04 36	12 06 31	at $12^h\ 0^m$ arc { 1°.52
02.5	55.3	46	41	temp. { 21°.0 { 1.42
12.5	05.3	56	51	{ 20.5
22.3	15.3	06.2	01	
32.3	25	16	11	bar. $30^{in}.204$ at 19°.7
A. S. 42.3	A. S. 35	A. S. 26	A. S. 21	The pendulum gained 6.6 vibra-
52.2	45	36	30.5	tions in an hour on the pocket
02.5	55	46	40.5	chronometer.
12.3	05	56	50.8	
22.2	15	06	00.8	at $0^h\ 8\frac{1}{2}^m$ arc { 1°.42
12 02 32	12 04 25	12 06 16	12 08 11	{ 1.26
0 01 42.33	0 03 35.08	0 05 26.02	0 07 20.87	
0 09 47.7	0 11 38.5	0 15 31	0 17 45.5	at $0^h\ 20^m$ arc { 1°.16
57.8	48.3	40.8	55.5	{ 1.05
07.6	58.2	50.9	05.6	
17.7	08.5	01	15.6	
27.7	18.4	11.1	25.5	
H. R. 37.6	H. R. 28.4	H. R. 21	H. R. 35.5	
47.5	38.2	31	45.4	
57.5	48.2	40.7	55.4	
07.6	58.3	50.6	05.6	
17.6	08.4	00.8	15.6	
0 11 27.5	0 13 18.3	0 17 10.9	0 19 25.5	
0 10 37.62	0 12 28.34	0 16 20.89	0 18 35.52	

L.	R.	L.	R.	
0 20 58	0 22 59	4 11 07	4 13 01.8	at $4^h\ 10^m$ arc $\{0°.19$
08.3	09.3	17	11.8	at $4^h\ 19^m$ temp. $\{24°\ 5$ $\ 0.03$
18.2	19	27	21.5	23.5
28	29	36.5	31.5	bar. $30^{in}.168$ at 25°.0
38	39	46.5	41.3	
A. S. 48	A. S. 49	A. S. 56.5	A. S. 51.2	
58.2	59	06.5	01.2	
08.2	09	16.8	11.3	
18.2	19	26.8	21.3	
28	29.8	36.5	31.3	
0 22 38	0 24 38.6	4 12 46.5	4 14 41.2	
0 21 48.10	0 23 48.97	4 11 56.72	4 13 51.40	
4 14 52	4 16 41	4 19 31.8	4 21 26.5	
02.3	51	41.7	36.6	
12.3	01	51.8	46.4	
22.2	11	01.8	56.5	
32	21	11.8	06.6	
A. S. 42	A. S. 31	H. R. 21.8	H. R. 16.6	
52	41	31.7	26.7	
02.3	51	41.7	36.4	
12.3	01	51.7	46.3	
22.2	11	01.8	56.5	
4 16 32	4 18 21	4 21 11.8	4 23 06.5	
4 15 42.15	4 17 31.00	4 20 21.76	4 22 16.51	
4 23 21.3	4 25 16.2			Chronometer comparisons
31.3	26.2		Pock. chron'r	$11^h\ 42^m\ 3^s.2 = 3^h\ 44^m$ by 2007
41.3	36.2			42 42.3 43 1062
51.2	46.1			43 22.2 44 740
01.3	56.2			
H. R. 11.4	H. R. 06.1			5 04 03.2 9 6 2007
21.2	16.2			04 42.0 5 1062
31.2	26			06 22.5 7 740
41.2	35.8			
51.1	46			Deduced hourly rate (between
4 25 01.4	4 26 56			11^h and 5^h) = + $^s.05$
4 24 11.26	4 26 06.09			

Experiments, set 15, face 4. October 11.

9 01 21	9 03 14	9 05 01	9 06 51.5	at $9^h\ 1^m$ arc $\{1°.73$
31.2	24	11	01.6	1.63
41	33.5	21	11.6	at $9^h\ 0^m$ temp. $\{15°.6$
51	43.5	30.8	21.5	17.0
01.3	54	40.8	31.5	bar. $29^{in}.843$ at 15°.0
A. S. 11	A. S. 04	A. S. 50.8	A. S. 41.3	
21	14	01	51.5	
31	24	11	01.5	
41	33.8	21	11.5	
51	43.8	30.8	21.5	at $9^h\ 9^m$ arc $\{1°.50$
9 03 01.2	9 04 53.8	9 06 40.8	9 08 31.3	1.42
9 02 11.06	9 04 03.85	9 05 50.91	9 07 41.48	

L.	R.	L.	R.	
9 11 00.4	9 12 51.1	9 14 58	9 16 48.5	at 9^h 20^m arc {1°.32
10.5	01.2	08	58.6	1.22
20.4	11.2	17.9	08.7	
30.2	21.1	28	18.6	
40.2	31.1	37.8	28.7	
H. R. 50.2	H. R. 41.1	H. R. 47.7	H. R. 38.6	
00.2	51.1	57.9	48.6	
10.3	01.1	08	58.5	
20.3	11.1	17.9	08.7	
30.2	21	27.7	18.6	
9 12 40.2	9 14 31	9 16 37.7	9 18 28.6	
9 11 50.28	9 13 41.10	9 15 47.87	9 17 38.61	
1 11 09	1 12 57.8	1 14 48.3	1 16 39	at 1^h 14^m arc {0°.18
19	07.8	58.3	40	at 1^h 10^m temp. {20°.0 {0.03
28.5	17.8	08.3	59	20.0
38.8	27.5	18.3	09.2	bar. $29^{in}.805$ at 22.3
48.8	37.5	28.3	19	
A. S. 58.8	A. S. 47.5	A. S. 38	A. S. 29	
08.8	57.5	48.3	39	
18.8	07.5	58.3	49	
28.8	17.5	08.2	59	
38.8	27.5	18.2	09	at 1^h 19^m arc {0°.14
1 12 48.8	1 14 37.5	1 16 28	1 18 19.2	0.06
1 11 58.81	1 13 47.58	1 15 38.23	1 17 29.04	
1 19 16.1	1 21 04.9	1 22 53.6	1 24 42.2	
26.1	14.9	03.8	52.3	Chronometer comparisons
36	24.8	13.8	02.3	Pock. Chronom'r
46	34.7	23.5	12.3	8^h 24^m $05^s.0$ = 0^h 26^m by 2007
56	44.6	33.5	22.2	24 42.9 25 1062
H. R. 06	H. R. 54.7	H. R. 43.5	H. R. 32.1	25 23.1 26 740
16.1	04.8	53.5	42.1	
26.1	14.8	03.5	52.1	0 57 5.7 4 59 2007
35.8	24.7	13.5	02.2	58 42.8 4 59 1062
45.7	34.6	23.4	12.2	59 23.8 5 00 740
1 20 55.8	1 22 44.5	1 24 33.3	1 26 22.1	Deduced hourly rate (between
1 20 05.97	1 21 54.73	1 23 43.54	1 25 32.19	8^h and 1^h) = $-^s.06$

Experiments, set 16, face 1. October 11.

1 47 43	1 49 32	1 51 22.5	1 53 13.5	at 1^h 47^m arc {1°.73
53.2	42	32.5	23.8	1.63
03.2	52	42.5	33.5	at 1^h 40^m temp. {23°.7
13.2	02	52.5	43.5	22.0
23	12	02.8	53.5	bar. $29^{in}.804$ at 28°.0
A. S. 33	A. S. 22	A. S. 12.8	A. S. 03.5	
43	32	22.8	13.5	
53	41.8	32.5	23.5	
03	52	42.5	33.5	
13	02	52.5	43.5	at 1^h $55\frac{1}{2}^m$ arc {1°.54
1 49 23	1 51 12	1 53 02.8	1 54 53.5	1.42
1 48 33.05	1 50 21.98	1 52 12.61	1 54 03.53	

L.	R.	L.	R.	
1 56 32.3	1 58 25.1	2 00 14	2 02 00.8	at $2^h\ 4^m$ arc { 1°.32
42.2	35	23.8	10.8	{ 1.26
52.2	45	33.8	20.7	
02.3	55.1	43.6	30.6	
12.2	05.2	53.7	40.5	
H. R. 22.2	H. R. 15	H. R. 03.9	H. R. 50.4	
32.1	25.1	13.8	00.6	
42.2	35	23.8	10.7	
52.1	44.8	33.8	20.6	
02.2	55	43.5	30.6	
1 58 12.3	2 00 05	2 01 53.6	2 03 40.5	
1 57 22.21	1 59 15.03	2 01 03.75	2 02 50.62	
6 08 42.2	6 10 32.8	6 12 31.8	6 14 20.5	at $6^h\ 8^m$ arc { 0°.13
52	42.8	41.8	30.5	at $6^h\ 10^m$ temp. { 24°.5 { 0.08
02.2	52.8	51.8	40.5	{ 23.0
12.2	02.8	02	50.5	bar. $29^{in}.786$ at 24°.0
22.3	12.8	11.8	00.5	
A. S. 32	A. S. 22.8	A. S. 21.8	A. S. 10.6	
42	32.8	31.8	20.5	
52	42.8	41.5	30.5	
02.3	52.8	51.5	40.5	
12.2	02.8	01.8	50.3	at $6^h\ 17^m$ arc { 0°.12
6 10 22	6 12 12.8	6 14 11.5	6 16 00.5	{ 0.08
6 09 32.13	6 11 22.80	6 13 21.65	6 15 10.49	
6 17 09.3	6 19 02.2	6 20 49	6 22 39.6	
19.4	12.2	59	49.7	
29.2	22.1	09	59.8	
39.2	31.9	19	09.8	
49.2	42	28.9	19.7	
H. R. 59.2	H. R. 52.1	H. R. 38.7	H. R. 29.5	
09.4	02.2	48.8	39.6	Chronometer comparisons
19.3	12.2	58.6	49.5	Pock. Chronom'r
29.1	22	08.8	59.5	$5^h\ 51^m\ 06^s.5 = 9^h\ 55^m$ by 2007
39.1	31.8	18.8	09.6	52 43 4 53 1062
6 18 49.1	6 20 41 8	6 22 28.7	6 24 19.5	54 25.8 55 740
6 17 59.23	6 19 52.05	6 21 38.85	6 23 29.62	Deduced hourly rate (between 1^h and 6^h) = — $^s.19$
Experiments, set 17, face 3. October 12.				
10 19 25.5	10 21 14.3	10 23 03	10 24 56	at $10^h\ 19^m$ arc { 1°.56
35.5	24.3	13	06	{ 1.47
45 3	34	23	16	at $10^h\ 18^m$ temp. { 19°.4
55.5	44	33	25.8	{ 19.2
05.5	54	43	35 8	bar. $20^{in}.374$ at 19.6
A. S. 15.5	A. S. 04.2	A. S. 53	A. S. 45.8	
25.5	14.2	03	55.8	
35.3	24	13	05.8	
45.3	34	23	15.8	
55.3	44	33	25.6	at $10^h\ 27^m$ arc { 1°.39
10 21 05.3	10 22 54	10 24 42.8	10 26 35.6	{ 1.30
10 20 15.41	10 22 04.09	10 23 52.98	10 25 45.82	

L.	R.	L.	R.	
10 27 54.8	10 29 43.3	10 31 33.9	10 33 34.8	at $10^h\ 36^m$ arc 1°.27
04.9	53.3	44	44.7	1.15
14.8	03.4	54.1	54.8	
24.7	13.4	04.3	14.9	
34.5	23.2	14.2	24.6	
H. R. 44.4	H. R. 33.2	H. R. 24	H. R. 34.5	
54.6	43.2	33.8	44.7	
04.7	53.2	43.8	54.8	
14.5	03.3	54	04.8	
24.4	13.2	04.1	14.8	
10 29 34.3	10 31 23.2	10 33 14.1	10 35 24.6	
10 28 44.60	10 30 33.26	10 32 24.03	10 34 24.73	
2 42 35	2 44 30	2 46 18.5	2 48 09.5	at $2^h\ 42^m$ arc 0°.19
44.8	39.8	28.3	19	temp. 23°.0 — 0.02
54.8	49.5	38.3	29.2	21.3
04.8	59.5	48.3	39	bar. $29^{in}.430$ at 50°.0
14.8	09.8	58.2	49	
A. S. 24.8	A. S. 19.5	A. S. 08.3	A. S. 59.2	
34.5	29.5	18.2	09	
44.5	39.5	28.2	19	
54.8	49.5	38	29	
04.8	59.5	48	39	at $2^h\ 50^m$ arc 0°.15
2 44 14.8	2 46 09.5	2 47 58.2	2 49 49	0.05
2 43 24.76	2 45 19.60	2 47 08.23	2 48 59.08	
2 51 06	2 52 56.8	2 54 45.4	2 56 32	
16.1	06.8	55.4	42.2	Chronometer comparisons
26	16.8	05.5	52.2	Pock. chronom'r
35.8	26.8	15.4	02.2	$9^h\ 57^m\ 10^s.5 = 1^h\ 59^m$ by 2007
45.7	36.5	25.4	12.3	57 46.7 58 1062
H. R. 55.8	H. R. 46.5	H. R. 35.2	H. R. 22.2	58 27.7 59 740
05.8	56.6	45.3	32	
15.8	06.7	55.3	42	2 23 11.8 6 25 2007
25.8	16.6	05.4	52.1	23 47.7 24 1062
35.7	26.6	15.3	02.2	24 28.7 25 740
2 52 45.7	2 54 36.5	2 56 25.3	2 58 12.2	Deduced hourly rate (between
2 51 55.84	2 53 46.65	2 55 35.35	2 57 22.15	10^h and 2^h) = — $0^s.20$

The following table contains the individual results of the observed number of vibrations in a given interval. The first column indicates left or right vibrations, alternately; the second gives the chronometer intervals derived from the preceding means of each set of observations; the third contains the correction for rate of chronometer for the intervals; the fourth the intervals corrected for rate and expressed in seconds of mean time; the fifth the corresponding number of vibrations. These were obtained by working out for each of the 16 sets the number of vibrations the pendulum gained upon the seconds of the chronometer in one hour, thus confining our attention to the successive means of the preceding record and their elapsed times, and subtracting the fraction of seconds of each from the preceding mean (remarking whether the seconds are odd or even) we find, by taking the differences of seconds and corresponding elapsed times collectively, the number of

vibrations in excess of a certain chronometer interval expressed in seconds. When reduced to the corresponding value for one hour, we have—

For face 1 . . . 6.61
" 3 . . . 7.14
" 4 . . . 6.52
" 2 . . . 6.72

and on the average 6.75 vibrations in excess of the number of seconds in an hour. It appears that the rate of the chronometer in sets 1, 3, 7, and 15 differed most from this mean, the 1st and 15th falling short of it, and the other two exceeding it; the number of vibrations for these sets were deduced under the supposition that the motion of the pendulum was more regular than that of the pocket chronometer. The following three columns contain the corrections for arc, temperature, and atmospheric pressure, as explained above. The last column shows the number of vibrations of the pendulum in a mean solar day.

	Chronometer intervals.	Corr'n for rate.	Mean time intervals.	No. of vib'ns.	Corresp. No. in a day.	Corrections for arc.	temp.	atm. pr.	N.
				Set 1. Face 1. September 26, 1860.					
L.	3^h 51^m $59^s.33$	$-1^s.16$	$13918^s.17$	13944	86560.36	+1.06	—11.62	—.01	86549.79
R.	3 51 49.10	—1.16	13907.94	13934	61.88	.96	"	"	51.21
L.	4 00 10.27	—1.20	14409.07	14436	61.48	.90	"	"	50.75
R.	3 59 44.09	—1.20	14382.89	14410	62.84	.84	"	"	52.05
L.	3 59 42.34	—1.20	14381.14	14408	61.36	.75	"	"	50.48
R.	3 59 42.17	—1.20	14380.97	14408	62.38	.70	"	"	51.45
						Mean . . .			86550.95
				Set 2. Face 1. September 26.					
L.	3 19 48.80	+ .47	11989.27	12012	86563.80	+ .76	—11.84	—.02	86552.70
R.	3 19 48.40	+ .47	11988.87	12012	66.68	.72	"	"	55.54
L.	3 19 30.42	+ .47	11970.89	11994	66.76	.67	"	"	55.57
R.	3 19 18.60	+ .47	11959.07	11982	65.66	.64	"	"	54.44
L.	3 18 24.83	+ .46	11905.29	11928	64.80	.58	"	"	53.52
R.	3 18 16.66	+ .47	11897.13	11920	66.08	.55	"	"	54.77
						Mean . . .			86554.42
				Set 3. Face 1. September 27.					
L.	4 18 26.99	+ .09	15507.08	15536	86561.12	+1.16	—13.79	—.02	86548.47
R.	4 17 58.98	+ .09	15479.07	15508	61.46	1.08	"	"	48.73
L.	4 16 49.36	+ .08	15409.44	15438	60.14	.96	"	"	47.29
R.	4 16 45.02	+ .08	15405.10	15434	62.08	.90	"	"	49.17
L.	4 14 23.18	+ .08	15263.26	15292	62.68	.74	"	"	49.61
R.	4 13 37.43	+ .08	15217.51	15246	61.74	.70	"	"	48.63
L.	4 13 07.54	+ .08	15187.62	15216	61.42	.67	"	"	48.28
R.	4 12 35.34	+ .08	15155.42	15184	62.92	.63	"	"	49.74
						Mean . . .			86548.74

	Chronometer intervals.	Corr'n for rate.	Mean time intervals.	No. of vib'ns.	Corresp. No. in a day.	Corrections for arc.	temp.	atm. pr.	N.
				Set 4. Face 3. September 28.					
L.	4^h 09^m $38^s.94$	+ $^s.21$	$14979^s.15$	15008	86566.40	+ .68	—11.66	—.10	86555.32
R.	4 09 36.92	+ .21	14977.13	15006	66.52	.66	"	"	55.42
L.	4 09 30.92	+ .21	14971.13	15000	66.60	.64	"	"	55.48
R.	4 09 33.09	+ .21	14973.30	15002	65.62	.61	"	"	54.47
L.	4 08 53.09	+ .21	14933.30	14962	66.04	.56	"	"	54.84
R.	4 08 56.97	+ .21	14937.18	14966	66.68	.53	"	"	55.45
L.	4 09 20.86	+ .21	14961 07	14990	67.60	.50	"	"	56.34
R.	4 09 12.82	+ .21	14953.03	14982	67.40	.49	"	"	56.13
						Mean . . .			86555.43
				Set 5. Face 3. September 29.					
L.	4 05 35.07	— .70	14734.37	14762	86562.20	+ .96	—15.64	—.05	86547.47
R.	4 05 52.88	— .70	14752.18	14780	62.92	.93	"	"	48.16
L.	4 05 58.76	— .70	14758.06	14786	63.56	.88	"	"	48.75
R.	4 05 52.95	— .70	14752.25	14780	62.52	.84	"	"	47.67
L.	4 05 34.86	— .70	14734.16	14762	63.24	.78	"	"	48.33
R.	4 05 18.98	— .69	14718.29	14746	62.64	.74	"	"	47.69
L.	4 05 05.00	— .69	14704.31	14732	62.70	.70	"	"	47.71
R.	4 05 02.93	— .69	14702.24	14730	63.12	.66	"	"	48.09
						Mean . . .			86547.98
				Set 6. Face 3. October 2.					
L.	4 03 14.52								
R.	4 03 24.35								
L.	4 03 20.44								
R.	4 03 18.28	This set is not used, owing to a defect in the indications of the chronometer.							
L.	4 02 02.31								
R.	4 01 24.44								
L.	4 01 08.42								
R.	4 01 04.30								
				Set 7. Face 3. October 2.					
L.	4 21 20.33	+ .22	15680.55	15710	86562.26	+ .83	—11.44	+.01	86551.66
R.	4 21 30.22	+ .22	15690.44	15720	62.76	.79	"	"	52.12
L.	4 21 39.93	+ .22	15700.15	15730	64.26	.74	"	"	53.57
R.	4 21 38.02	+ .22	15698.24	15728	63.80	.70	"	"	53.07
L.	4 21 22.21	+ .22	15682.43	15712	62.92	.65	"	"	52.14
R.	4 21 56.11	+ .22	15716.33	15746	63.10	.62	"	"	52.29
L.	4 22 06.17	+ .22	15726.39	15756	62.68	.61	"	"	51.86
R.	4 22 12.08	+ .22	15732.30	15762	63.10	.60	"	"	52.27
						Mean . . .			86552.37

	Chronometer intervals.	Corr'n for rate.	Mean time intervals.	No. of vib'ns.	Corresp. No. in a day.	Corrections for arc.	temp.	atm. pr.	N.
				Set 8. Face 4. October 3.					
L.	3^h 57^m $56^s.95$	+ $^s.24$	$14277^s.19$	14304	86562.24	+1.07	—13.92	.00	86549.39
R.	3 57 54.65	+ .24	14274.89	14302	64.10	1.03	"	"	51.21
L.	3 57 54.87	+ .24	14275.11	14302	62.76	.96	"	"	49.80
R.	3 57 54.73	+ .24	14274.97	14302	63.60	.92	"	"	50.60
L.	3 56 49.06	+ .24	14209.30	14236	62.34	.80	"	"	49.22
R.	3 56 43.03	+ .24	14203.27	14230	62.60	.77	"	"	49.45
L.	3 56 44.98	+ .24	14205.22	14232	62.88	.74	"	"	49.70
R.	3 57 12.84	+ .24	14233.08	14260	63.42	.71	"	"	50.21
						Mean . . .			86549.95
				Set 9. Face 4. October 4					
L.	4 34 44.14	— .96	16483.18	16514	86561.54	+ .78	—11.58	+.06	86550.80
R.	4 34 51.71	— .96	16490.75	16522	63.72	.74	"	"	52.94
L.	4 34 51.92	— .96	16490.96	16522	62.60	.71	"	"	51.79
R.	4 34 54.02	— .96	16493.06	16524	62.06	.68	"	"	51.22
L.	4 35 45.69	— .96	16544.73	16576	63.28	.63	"	"	52.39
R.	4 35 47.70	— .96	16546.74	16578	63.22	.60	"	"	52.30
L.	4 35 43.84	— .96	16542.88	16574	62.52	.57	"	"	51.57
R.	4 35 43.82	— .96	16542.86	16574	62.62	.55	"	"	51.65
						Mean . . .			86551.83
				Set 10. Face 2. October 5.					
L.	4 47 40.09	+ .14	17260.23	17292	86559.02	+ .89	—10.40	+.05	86549.56
R.	4 47 47.93	+ .14	17268.07	17300	59.86	.85	"	"	50.36
L.	4 47 39.99	+ .14	17260.13	17292	59.52	.79	"	"	49.96
R.	4 47 39.95	+ .14	17260.09	17292	59.72	.76	"	"	50.13
L.	4 46 56.17	+ .14	17216.31	17248	59.02	.69	"	"	49.36
R.	4 47 08.17	+ .14	17228.31	17260	58.92	.66	"	"	49.23
L.	4 47 06.19	+ .14	17226.33	17258	58.84	.63	"	"	49.12
R.	4 47 12.05	+ .14	17232.19	17264	59.48	.61	"	"	49.74
						Mean . . .			86549.68
				Set 11. Face 2. October 6.					
L.	4 26 44.65	— .04	16004.61	16034	86558.66	+ .77	—11.89	—.01	86547.53
R.	4 26 42.44	— .04	16002.40	16032	59.80	.73	"	"	48.63
L.	4 26 38.69	— .04	15998.65	16028	58.48	.69	"	"	47.27
R.	4 26 30.53	— .04	15990.49	16020	59.46	.65	"	"	48.21
L.	4 24 18.62	— .04	15858.58	15888	60.28	.57	"	"	48.95
R.	4 24 20.45	— .04	15860.41	15890	61.16	.55	"	"	49.81
L.	4 23 54.63	— .04	15834.59	15864	60.48	.53	"	"	49.11
R.	4 24 02.64	— .04	15842.60	15872	60.36	.50	"	"	48.96
						Mean . . .			86548.56

	Chronometer intervals.	Corr'n for rate.	Mean time intervals.	No. of vib'ns.	Corresp. No. in a day.	Corrections for arc.	temp.	atm. pr.	N.
				Set 12. Face 2. October 8.					
L.	4h 08m 14s.45	+ s.37	14894s.82	14922	86557.66	+1.00	—10.67	+.08	86548.07
R.	4 08 20.32	+ .37	14900.69	14928	58.34	.95	"	"	48.70
L.	4 08 12.25	+ .37	14892.62	14920	58.84	.91	"	"	49.16
R.	4 07 38.37	+ .37	14858.74	14886	58.50	.86	"	"	48.77
L.	4 07 10.38	+ .37	14830.75	14858	58.76	.81	"	"	48.98
R.	4 07 14.42	+ .37	14834.79	14862	58.48	.78	"	"	48.67
L.	4 06 54.53	+ .37	14814.90	14842	58.02	.75	"	"	48.18
R.	4 06 42.65	+ .37	14803.02	14830	57.48	.71	"	"	47.60
						Mean . . .			86548.52
				Set 13. Face 2. October 9.					
L.	4 12 23.89	+ .13	15144.02	15172	86559.62	+ .91	—10.35	+.11	86550.29
R.	4 12 21.89	+ .13	15142.02	15170	59.66	.86	"	"	50.28
L.	4 12 21.82	+ .13	15141.95	15170	60.08	.83	"	"	50.67
R.	4 12 25.67	+ .13	15145.80	15174	60.86	.76	"	"	51.38
L.	4 11 57.89	+ .13	15118.02	15146	59.92	.70	"	"	50.38
R.	4 12 05.97	+ .13	15126.10	15154	59.36	.67	"	"	49.79
L.	4 12 01.91	+ .13	15122.04	15150	59.76	.63	"	"	50.15
R.	4 12 05.92	+ .13	15126.05	15154	59.66	.60	"	"	50.02
						Mean . . .			86550.37
				Set 14. Face 4. October 10.					
L.	4 10 14.39	+ .21	15014.60	15042	86557.68	+ .66	—12.52	+.14	86545.96
R.	4 10 16.32	+ .21	15016.53	15044	58.04	.65	"	"	46.31
L.	4 10 16.13	+ .21	15016.34	15044	59.14	.62	"	"	47.38
R.	4 10 10.13	+ .21	15010.34	15038	59.22	.60	"	"	47.44
L.	4 09 44.14	+ .21	14984.35	15012	59.44	.55	"	"	47.61
R.	4 09 48.17	+ .21	14988.38	15016	59.22	.52	"	"	47.36
L.	4 07 50.37	+ .20	14870.57	14898	59.38	.45	"	"	47.45
R.	4 07 30.57	+ .20	14850.77	14878	58.44	.43	"	"	46.49
						Mean . . .			86547.00
				Set 15. Face 4. October 11.					
L.	4 09 47.75	— .25	14987.50	15016	86564.30	+ .82	—14.42	+.02	86550.72
R.	4 09 43.73	— .25	14983.48	15012	64.46	.78	"	"	50.84
L.	4 09 47.32	— .25	14987.07	15016	66.78	.74	"	"	53.12
R.	4 09 47.56	— .25	14987.31	15016	65.40	.68	"	"	51.68
L.	4 08 15.69	— .25	14895.44	14924	65.64	.62	"	"	51.86
R.	4 08 13.63	— .25	14893.38	14922	66.02	.59	"	"	52.21
L.	4 07 55.67	— .25	14875.42	14904	65.98	.57	"	"	52.15
R.	4 07 53.58	— .25	14873.33	14902	66.52	.55	"	"	52.67
						Mean . . .			86551.91

	Chronometer intervals.	Corr'n for rate.	Mean time intervals.	No. of vib'ns.	Corresp. No. in a day.	Corrections for arc.	temp.	atm. pr.	N.
				Set 16. Face 1. October 11.					
L.	4^h 20^m $59^s.08$	— $^s.82$	$15658^s.26$	15688	86564.10	+ .79	—12.11	.00	86552.78
R.	4 21 00.82	— .82	15660.00	15690	65.50	.76	"	"	54.15
L.	4 21 09.04	— .82	15668.22	15698	64.20	.72	"	"	52.81
R.	4 21 06.96	— .82	15666.14	15696	64.68	.69	"	"	53.26
L.	4 20 37.02	— .82	15636.20	15666	64.66	.64	"	"	53.19
R.	4 20 37.02	— .82	15636.20	15666	64.66	.61	"	"	53.16
L.	4 20 35.10	— .82	15634.28	15664	64.22	.58	"	"	52.69
R.	4 20 39.00	— .82	15638.18	15668	64.76	.55	"	"	53.20
						Mean . . .			86553.15
				Set 17. Face 3. October 12.					
L.	4 23 09.35	— .88	15788.47	15818	86561.60	+ .67	—13.24	—.15	86548.88
R.	4 23 15.51	— .88	15794.63	15824	60.68	.64	"	"	48.93
L.	4 23 15.25	— .88	15794.37	15824	62.08	.61	"	"	49.30
R.	4 23 13.26	— .88	15792.38	15822	62.04	.59	"	"	49.24
L.	4 23 11.24	— .88	15790.36	15820	62.18	.55	"	"	49.34
R.	4 23 13.39	— .88	15792.51	15822	61.32	.53	"	"	48.46
L.	4 23 11.32	— .88	15790.44	15820	61.74	.52	"	"	48.87
R.	4 22 57.42	— .88	15776.54	15806	61.32	.50	"	"	48.43
						Mean . . .			86548.93

We therefore have the following resulting number of vibrations performed at Port Foulke in a mean solar day, the temperature of the pendulum being at 50° Fah., and the atmospheric pressure 29.8 inches (with the mercury at the temperature of freezing water).

First position of pendulum.	After reversal end for end.
Face 4 swinging, 86550.17	Face 1 swinging, 86551.81
Face 2 " 86549.28	Face 3 swinging, 86551.18
Mean, 86549.72	Mean, 86551.50

Mean of two positions	86550.61
Correction for 40 feet elevation above half tide	+ 0.11
Resulting number of vibrations at the level of the sea in the latitude of Port Foulke	86550.72
The Port Foulke Observatory is in latitude	78° 17′ 39″

At Cambridge we have an excess of 2.68 vibrations in a day in the second position when compared with the first; at Port Foulke this excess is 1.78 vibration, from which numbers we infer that the pendulum has undergone no change.

Finally we have from the relation of $g : g_1 = \mathrm{N}^2 : N_1^2$ force of gravity at Cambridge to force of gravity at Port Foulke as $(86419.64)^2$ to $(86550.72)^2$; however, if we reject the number of vibrations at Cambridge, face 4 swinging, as too small, since at Port Foulke the number for this position is quite accordant with the num-

bers of the remaining positions, we have to combine the mean of faces 1 and 3, or 86420.76 with face 2, or 86421.08, we find 86420.92, and adding the correction for elevation we have the proportion $g : g_1 = (86421.14)^2 : (86550.72)^2$.

Bearing of Preceding Pendulum Experiments on the Value for the Earth's Compression.—If there was no local disturbance in the force of gravity arising from irregular distribution and various densities of masses in the vicinity of the station, the observed number of vibrations at any two stations remote in latitude would suffice to deduce the earth's compression, and in proportion as we increase the number of pendulum stations the deduced value for the compression will gain in reliability, it being improbable that the local disturbances should all tend the same way. From two stations only we can obtain but a first approximation, thus from our observations

let N_1 = observed number of vibrations in a mean solar day in latitude ϕ_1
N_{11} = " " " " " " ϕ_{11}
N = number of vibrations in the same interval at the equator
n = a function of the earth's ellipticity

then the relation $N_0^2 = N^2\,(1 + n \sin^2 \phi_0)$ furnishes the two equations

$$(86421.14)^2 = N^2\,(1 + n \sin^2 42°\ 22'\ 51''.5)$$
$$(86550.72)^2 = N^2\,(1 + n \sin^2 78\ \ 17\ \ 39\ \ \ )$$

and solving these, we find for the *Hayes* pendulum $N = 86304.26$ and $n = 0.005965$. We have further by Clairaut's theorem

$$n = \frac{5}{2 \times 289} - c \qquad \text{whence } c = \frac{a - b}{b} \qquad \text{hence } c = \frac{1}{372}$$

a value very much smaller than that arising from the assemblage of the best pendulum results ($\frac{1}{285}$, Baily in Vol. VII, Mem. Roy. Ast. Soc.), but if combined with them would tend to diminish the value of c, and bring it nearer to that found from the geodetic measures ($\frac{1}{293}$ Lt. Col. James, Account of the Ordnance Trigonometrical Survey of Great Britain and Ireland, London, 1858). Values as small as that found above have, however, been observed before, see "an account of experiments for determining the variation in the length of the seconds pendulum at the principal stations of the trigonometrical survey of Great Britain. By Cap. H. Kater." Phil. Trans. Roy. Soc., 1819, Part 3, p. 423; also "Figure of the Earth," by G. B. Airy, Ast. Roy., Encyclopædia Metropolitana, 1830, p. 230. According to Baily's formula $V = (7441625711 + 38286335 \sin^2 L)^{\frac{1}{2}}$ we should have nearly 112 vibrations more at Port Foulke than at Cambridge, whereas by direct observation we have 131 nearly.[1]

Respecting the horizontality of the supporting plates of the Hayes' pendulum, the record at either station makes no mention, but as a deviation can easily be detected, I do not apprehend any source of error on this account. A special

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[1] The maximum increase in the number of vibrations (in a day) of the seconds pendulum is about half the number of seconds in the maximum deflection of the plumbline (Capt, Clarke in Lt. Col. James' Ordnance Survey, pp. 590 and 594).

examination was made of the perpendicularity of the knife-edges to the longitudinal axis of the pendulum, also of their plane which should pass through the same axis —the test was found satisfactory. On this part of the theory of the physical pendulum, the paper "On the Pendulum," by J. W. Lubbock, Phil. Trans. Roy. Soc., 1830, Part 1, p. 201, may be consulted. There is reason to suppose that the support of the pendulum case at the stations was sufficiently massive to guard against induced vibrations. A fine mark on the supporting plate seems to have been used to secure an identical contact with the knife-edges; there are also two guiding pins to indicate the central position of the bar between the plates. The plates show no wear, and the knife-edges appear in perfect condition.

It is very desirable that the Hayes' pendulum be swung at a number of other stations[1] for the purpose of combining the results, and if possible to connect them with the accumulated series given by Baily. The connection could be made by swinging the pendulum at Captain Sabine's station of 1822–23 in New York City (or as near to it as possible, since the old site of the Columbia College is now inaccessible to such operations. Localities like Washington, D. C., and Key West, Florida, would be well suited for new observations, and if combined with any made at New York would furnish a valuable contribution to our present knowledge of the earth's compression as resulting from experiments of vibrations.

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[1] As pendulum observations have a direct bearing upon the larger geodetic operations for ascertaining the earth's figure, and have recently again been considered for introduction in the Russian and Indian arcs, I have taken occasion to bring the desirability of swinging the pendulum at some stations of the United States Coast Survey, to the favorable consideration of the Superintendent.


CHART
Showing the Vicinity of
PORT FOULKE,
The Winterquarters, in 1860-1861, of the Arctic Exploring Expedition of
Dr. I. I. HAYES.
Reduced and projected from original chart, for the Smithsonian Institution, by
CHARLES A. SCHOTT,
U. S. C. S.
1865.
Scale 1 : 170,000
73° W. of G.
SMITH STRAIT
HARTSTENE BAY
MER DE GLACE
Dodges Mountains
Hills from 2000 to 2500 feet high
McGary Is'd.
Littleton Is'd.
Cape Ohlsen
Life Boat Cove
Sunrise Pt.
Jensen Pt.
Reindeer Pt.
Numerous Reindeer
Etah—Esquimaux Village
Foulke Fiord
Alida Lake
Brother John's glacier
Doctor Hayes' track Oct. 1860
Sunken Rock
Radcliff Id.
Star Id.
Knorr Id.
Port Foulke
Observ'y
Harris Hill
Sonntags' Monument
Mount Aubrey
L. Julius' Glen & Fall
Numerous Reindeer
Cape Kenrick
McCormick's Bight
Heywood Hill
Crystal Palace Cliffs
Esquimaux Hut
Crystal Palace Glacier
Cape Alexander
Sutherland Is'd
78°20′
78°15′
78°10′
73 50′
40′
30′
20′
10′
73°00′
50′
40′
30′
20′
72°10′
0 1 2 3 4 5 St. miles
0 1 2 3 4 5 6 7 8 9 10 Kilom'r

PART II.

MAGNETIC OBSERVATIONS.

RECORD AND RESULTS

OF

MAGNETIC OBSERVATIONS.

Introductory Remarks.—The present, second part, of the records and results of the Arctic Expedition of 1860 and 1861, commanded by Dr. Hayes, will contain the magnetic observations and their discussion.

These observations will be given under the heads "differential observations" and "absolute determinations. The former comprise a series of hourly readings of the declinometer on 15 days between November, 1860, and March, 1861, at Port Foulke, the winter quarters of the expedition; also three daily readings, for the same period, at stated hours. The latter class of observations includes many determinations of the declination, the dip, and the intensity of terrestrial magnetism at stations in the north of Greenland, on Smith Strait, and northward on Smith Sound. The declinations were chiefly determined by means of solar bearings, but there are also a few determinations with the declinometer.

The magnetometer (or declinometer) and dip circle, and a Smalkalder azimuth compass, used by the expedition, were furnished by the liberality of Prof. A. D. Bache, Superintendent United States Coast Survey. Besides these instruments, the expedition was provided with two small compasses and other ordinary ones; one small azimuth compass was loaned by the Bureau of Topographical Engineers.

Description of Instruments.—The magnetometer, made by W. H. Jones, of London, has an azimuth circle of six inches diameter, and can be read to 20″ by means of the verniers. The magnet is suspended in a box over the centre of the circle, the suspension tube is eight inches long. Two magnets, each three inches long and 0.3 inch in diameter, with mirror attached, are provided, also a collimater magnet $3\frac{1}{2}$ inches long, and but 0.3 inch of outer diameter. Ordinarily the ivory scale above the eye end of the telescope is used for reading the deflections when mirror magnets are suspended, for the determination of absolute declinations an extra telescope can be fastened to the projecting arm of the alidade, the collimater magnet is then suspended, the glass scale of which is illuminated by a small reflector. An inertia ring, thermometer, and other necessaries are also provided. The dip circle was made by Patton, of Washington, new needles have been supplied by Mr. Würdemann, they are about 8 inches in length. There are also two magnets for the reversals of the poles. A three legged stand accompanied these instruments.

For the instrumental constants, see determinations further on. Würdemann's prismatic azimuth compass reads from south through east to 360°; the other small compass reads from north to west.

The magnetic observations were commenced by Mr. A. Sonntag; after his death, in December, 1860, the care of the magnetic determinations devolved upon Mr. H. G. Radcliff, who was assisted by Messrs. C. C. Starr and G. F. Knorr, and also by the commander of the expedition.

The instrumental constants necessary for deducing the results for horizontal force and for scale value of the differential observations were made by me in Washington in June, 1862.

The geographical positions and chronometer corrections required in the discussion will be taken from the preceding astronomical paper (Part I of the scientific contributions by the expedition) without further special reference.

DIFFERENTIAL OBSERVATIONS AT PORT FOULKE.

These observations were made at the observatory (of which a general description has already been given); Dr. Hayes wrote to me the following note respecting the mounting of the instrument. "The magnetometer was mounted in the centre of the room upon a stand made of two kegs whose heads being removed, and the ends carefully fitted together, were filled with beans and water. These were of course soon frozen into a solid mass, and the lower keg being placed upon the solid rock through a hole cut in the floor, the support for the instrument was as firm as possible. No stove or other artificial means of warmth was at any time used."

Diurnal Variation of the Magnetic Declination.—For the purpose of investigating the diurnal march of the horizontal needle, hourly observations were recorded on 15 days, at Port Foulke, between November 26, 1860, and March 4, 1861. As the diurnal excursions of the magnet frequently exceed the range of the scale fastened to the telescope, the horizontal circle had to be shifted in order to bring the direction of the magnet at all times within central range of the telescopic scale; the record consists therefore of readings of the azimuth circle and of readings of the reflected scale. The observers are indicated by their initials, R. for Radcliff, K. for Knorr, and S. for Starr.

The instrument having been properly adjusted, the following readings were taken:—

Scale Readings of Declinometer.

Mean local time.	1860. Nov. 26–27.		Nov. 27.		Dec. 3–4.		Dec. 12–13.		Dec. 18–19.		Dec. 24–25.	
8 A.M.	$32^d.4$	R.	$28^d.3$	S.	$24^d.3$	R.	$35^d.4$	K.	$35^d.1$	K.	$34^d.2$	S.
9 "	25.3		28.2	R.	23.5		35.3		31.0		Inst. moved in cleaning	
10 "	30.9		26.5		26.1		35.2		33.8		38.3	
11 "	30.9		27.0		24.6		35.1		34.5		42.1	
Noon	35.8		28.9		25.5		35.1		33.7		44.2	
1 P.M.	35.0	K.	24.4	K.	25.2	K.	35.2	R.	34.3	R.	42.9	K.
2 "	34.8		25.1		25.9		35.5		33.3		43.0	
3 "	36.4		24.6		25.1		35.5		34.8		43.7	
4 "	36.5		26.4		25.9		35.0		34.3		44.1	
5 "	Inst't	S.			26.4	S.	35.2	K.	35.0	S.	44.5	R.
6 "	upset				25.1		35.1		34.5		44.6	
7 "	30.2				26.3		35.3		35.7		29.1	
8 "	31.1				27.3		35.5		36.0		29.4	
9 "	31.9	R.			27.5	R.	35.6	S.	36.2	K.	29.8	S.
10 "	31.7				27.5		35.7		36.9		29.9	
11 "	33.5				27.6		35.8		36.7		29.9	
Midn't	34.6				27.4		35.9		36.2		29.9	
1 A.M.	32.7	K.			27.8	S.	35.9	K.	35.8	S.	29.5	K.
2 "	33.2				27.9		35.9		35.0		29.3	
3 "	31.5				27.8		35.9		36.0		29.0	
4 "	32.3				27.7		35.9		37.0		30.2	
5 "	31.1	S.			27.3	K.	35.8	R.	36.2	R.	30.3	R.
6 "	29.4				27.6		35.6		35.1		30.4	
7 "	29.9				27.3		35.2		35.6		29.3	
8 "	28.3				27.2		35.2		35.1		28.1	

Corresponding Azimuth Circle Readings.

	8 A.M.	24° 40′	8 A.M.	33° 00′	8 A.M.	34° 20′	8 A.M.	33° 00′	8 A.M.	33° 00′	8 A.M.	33° 00′
	7 P.M.	33 00			10 "	34 50					10 "	25 00
											7 P.M.	29 00

Scale Readings.												
Mean local time.	1860. 1861. Dec.31. Jan. 1.		Jan'y 7–8.		Jan'y 14–15.		Jan'y 21–22.		Jan'y 28–29.		Feb'y 4–5.	
8 A.M.	27d.2	R.	28d.1	K.	27d.8	S.	32d.0	R.	33d.1	K.	33d.8	S.
9 "	27.2		28.1		28.3		29.7		33.0		33.9	
10 "	26.0		28.2		27.0		30 5		31.1		34.0	
11 "	26.1		28.3		27.5		30.6		31.5		34.0	
Noon	27.1		28.8		22.3		30.7		30.0		31.0	
1 P.M.	24.5	S.	27.9	R.	22.0	K.	31.8	S.	31.9	R.	32.4	K.
2 "	26.0		28.0		24.1		32.4		31.6		30.1	
3 "	23.9		27.7		24.5		32.7		34.4		29.8	
4 "	26.5		28.0		26.1		32.3		34.3		31.2	
5 "	27.8	K.	27.6	S.	24.9	R.	33.5	K.	34.6	S.	33.5	R.
6 "	28.3		27.7		27.0		34.0		34.7		34.1	
7 "	28.6		28.0		28.8		35.5		35.3		34.0	
8 "	29.1		28.4		28.6		35.6		35.0		34.9	
9 "	29.4	R.	29.3	K.	29.4	S.	36.2	R.	35.0	K.	35.4	S.
10 "	28.7		30.8		30.2		35.2		35.0		36.0	
11 "	28.7		30.5		29.5		35.3		35.0		35.5	
Midn't	29.3		30.8		30.4		35.3		35.4		34.9	
1 A.M.	29.0	S.	30.8	S.	30.4	K.	36.0	S.	34.7	R.	35.2	K.
2 "	29.1		30.4		30.1		37.0		34.8		36.1	
3 "	29.0		31.3		31.2		38.1		35.3		37.5	
4 "	28.4		29.6		29.1		38.0		35.0		36.4	
5 "	28.5	K.	30.6	R.	28.2	R.	37.6	K.	34.6	S.	36.5	R.
6 "	28.4		29.9		27.7		35.2		34.4		34.1	
7 "	28.1		28.9		27.5		33.7		34.4		34.2	
8 "	28.2		28.5		29.1		32.2		34.3		33.3	
Circle Readings.												
	8 A.M.	28° 00′	8 A.M.	28° 00′	8 A.M.	28° 00′	8 A.M.	27° 00′	8 A.M.	27° 00′	8 A.M.[1]	27° 00′

[1] Wind blowing from N. E. (true), and heavy snow drift during the observations.

Scale Readings.								
Mean local time.	February 11–12.		February 18–19.		February 25.		March 4–5.	
8 A. M.	$34^{d}.3$	R.	$34^{d}.6$	K.	$36^{d}.8$	S.	$39^{d}.1$	R.
9 "	36.9		35.9		35.4		38.1	
10 "	36.7		36.5		35.1		37.7	
11 "	31.7		36.1		35.3		37.8	
Noon	37.3		Instrument moved		36.8		35.4	
1 P. M.	33.9	S.	31.0	R.	37.0	K.	35.9	S.
2 "	35.8		30.1		38.3		35.1	
3 "	36.7		33.3		37.1		35.0	
4 "	35.1		35.8		35.8		35.2	
5 "	36.0	K.	35.1	S.	38.6	R	36.8	K.
6 "	38.6		35.2		38.5		38.1	
7 "	38.3		37.3		38.7		38.5	
8 "	39.0		37.8		38.8		38.0	
9 "	38.8	R.	37.9	K.	38.8	S.	39.3	R.
10 "	39.7		37.4		38.7		39.2	
11 "	39.3		38.6		38.6		38.9	
Midnight	41.6		40.3				39.5	
1 A. M.	43.1	S	37.2	R.			39.1	S.
2 "	39.9		36.6				39.3	
3 "	39.8		36.5				39.4	
4 "	36.6		36.7				38.5	
5 "	38.3	K.	37.0	S.			37.2	K.
6 "	38.0		36.2				38.1	
7 "	37.4		35.5				38.5	
8 "	35.9		33.0				38.8	
Circle Readings.								
	8 A. M.	26° 20′	8 A. M.	26° 20′	8 A. M.	26° 20′	8 A. M.	26° 20′
			1 P. M.	" "				
	Light wind and snow from S. W. (true) until 8 P. M., when the wind blew stronger and snow drifting.		Calm and clear during the above observations.		Wind blowing heavy from N. (true), and snow drifting. Observations discontinued at 11 P. M. on account of wind.		Clear, with wind from N. E. (true) during the above observations.	

We have now to express the preceding numbers in units of the same scale, and to refer them to the same zero for each day. The determination of the scale value at Washington gave 1 division $= 10'.14$ since in the present record the last figure is noted as a decimal. The given reading of the circle is taken to refer to the centre of the reflected scale or to the division 30, the excess above 30 converted into parts of a degree, has been added to the circle reading and the defect below 30, after conversion, has been subtracted from the circle reading, the latter being expressed in degrees and fraction of a degree.

Increasing scale numbers correspond to an *easterly* movement of the north end of the magnet; *increasing* circle readings are likewise in the direction from north to *east*. The correction for torsion (for deviations beyond 30.0 divisions) has been rejected by the observer as too small to affect the results.

The observations on November 26 and 27, 1860, will be omitted in the following table owing to the break in the series on the 26th, and the incompleteness on the 27th.

The first two readings, December 24, 1860, require to be changed to conform to the readings of the day; these readings, after conversion, are 33°.71 and 33°.71; they have been changed into 27°.42 and 27°.42 by the following process of interpolation: If we compare the readings December 24 at 10^h, 11, 12, 1, 2, 3^h, with the readings at the same hours on the three days of observation preceding, we find the corrections —6.31, —6.47, —6.64 to be applied to the latter to produce the series on December 24, and applying these quantities to the readings at 9 A. M., we find for that hour, December 24, 26°.96. Again, the mean reading at 9 A. M., before the break from 5 observations, is 33.34, and from 8 observations, after the break, 27.48, difference —5.86; and applying this to the actual reading December 24, 9 A. M., we find the value 27.85; the mean of these two values is 27.40. By the same process for 8 A. M., we find 27.44, the mean 27.42 is given in the table. The break in the series amounted therefore to 6°.29,

The value for noon, February 18, is the mean of the values for 11 P. M. and 1 P. M.; the instrument does not appear to have been permanently disturbed. The incomplete readings of February 25th are omitted.

Hourly readings of the declinometer at Port Foulke, expressed in degrees and fraction; increasing numbers denote a movement of the north end of the magnet towards the east.

1860 1861	Dec. 3–4.	Dec. 12–13.	Dec. 18–19.	Dec. 24–25.	Dec. 31 Jan. 1.	Jan. 7–8.	Jan. 14–15.	Jan. 21–22.	Jan. 28–29.	Feb. 4–5.	Feb. 11–12.	Feb. 18–19.	March 4–5.
8 A.M.	33.°37	33°.91	33°.86	27°.42	27°.53	27°.68	27°.63	27°.34	27°.53	27°.64	27°.06	27°.11	27°.88
9 "	33.24	33.89	33.17	27.42	27.53	27.68	27.71	26.95	27.51	27.66	27.49	27.32	27.70
10 "	34.17	33.87	33.64	26.73	27.32	27.70	27.49	27.08	27.19	27.68	27.46	27.42	27.63
11 "	33.92	33.86	33.76	27.38	27.34	27.71	27.58	27.10	27.25	27.68	26.62	27.36	27.65
Noon	34.07	33.86	33.63	27.72	27.51	27.80	26.70	27.12	27.00	27.17	27.56	26.93	27.24
1 "	34.02	33.87	33.73	27.51	27.08	27.64	26.65	27.30	27.32	27.41	26.99	26.50	27.32
2 "	34.13	33.92	33.56	27.52	27.32	27.66	27.01	27.41	27.27	27.02	27.30	26.35	27.19
3 "	34.00	33.92	38.81	27.64	26.97	27.61	27.08	27.46	27.75	26.97	27.46	26.89	27.17
4 "	34.13	33.84	33.73	27.71	27.41	27.66	27.34	27.39	27.73	27.21	27.19	27.30	27.21
5 "	34.22	33.87	33.84	27.78	27.63	27.59	27.14	27.59	27.78	27.59	27.34	27.19	27.47
6 "	34.00	33.86	33.76	27.80	27.71	27.61	27.49	27.68	27.80	27.70	27.78	27.21	27.70
7 "	34.20	33.89	33.96	27.85	27.76	27.66	27.80	27.92	27.89	27.68	27.73	27.56	27.76
8 "	34.37	33.92	34.01	27.90	27.85	27.73	27.76	27.94	27.84	27.83	27.86	27.64	27.68
9 "	34.41	33.94	34.04	27.97	27.90	27.88	27.90	28.04	27.84	27.91	27.81	27.66	27.91
10 "	34.41	33.96	34.16	27.98	27.78	28.13	28.03	27.87	27.84	28.01	27.98	27.58	27.89
11 "	34.42	33.97	34.13	27.97	27.78	28.08	27.92	27.89	27.84	27.92	27.91	27.78	27.83
Midn't	34.39	33.99	34.04	27.98	27.88	28.13	28.07	27.89	27.91	27.83	28.29	28.07	27.94
1 "	34.46	33.99	33.97	27.92	27.83	28.13	28.07	28.01	27.80	27.87	28.54	27.54	27.88
2 "	34.47	33.99	33.84	27.88	27.85	28.07	28.02	28.18	27.81	28.03	28.01	27.44	27.91
3 "	34.46	33.99	34.01	27.83	27 83	28.22	28.20	28.37	27.89	28.26	27.99	27.42	27.93
4 "	34.44	33.99	34.18	28.03	27.73	27.93	27.85	28.35	27.84	28.08	27.44	27.46	27.76
5 "	34.37	33.97	34.04	28.05	27.75	28.10	27.70	28.28	27.78	28.09	27.73	27.51	27.54
6 "	34.42	33.94	33.86	28.07	27.73	27.98	27.61	27.87	27.75	27.70	27.68	27.37	27.70
7 "	34.37	33.87	33.94	27.88	27.68	27.82	27.58	27.63	27.75	27.72	27.58	27.25	27.76
8 "	34.36	33.87	33.86	27 68	27.70	27.75	27.85	27.37	27.73	27.56	27.32	26.84	27.81

As the series is a short one, I give the separate means of 6 and of 7 days to compare with the mean of 13; these partial results confirm the general regularity of the diurnal variation, and show that we may place confidence in the result deduced from the aggregate values.

Diurnal Variation of the Magnetic Declination at Port Foulke, Smith Strait, December to March, 1860–61.

Mean local time.	Mean of 6 days.	Mean of 7 days.	Mean of 13 days.	Mean local time.	Mean of 6 days.	Mean of 7 days.	Mean of 13 days.
8 A. M.	30°.63	27°.46	28°.92	8 P. M.	30°.96	27°.79	29°.26
9	× 30.49	27.48	28.87	9	31.02	27.87	29.32
10	30.57	27.31	28.81	10	31.07	27.89	29.36
11	30.66	27.32	28.86	11	31.06	27.87	29.34
Noon	30.76	27.10	28.79	Midnight	‡ 31.07	28.00	‡ 29.42
1	30.64	× 27.07	× 28.72	1	31.05	27.96	29.38
2	30.68	27.08	28.74	2	31.02	27.92	29.35
3	30.66	24.25	28.83	3	31.06	‡ 28.01	‡ 29.42
4	30.75	24.34	28.91	4	31.05	27.83	29.31
5	30.82	27.44	29.00	5	31.05	27.80	29.30
6	30.79	27.62	29.08	6	31.00	27.67	29.21
7	30.89	27.76	29.20	7	30.93	27.61	29.14
				8	30.87	27.50	29.05

West elongations are indicated by a , and *east* elongations by ‡.

Taking the mean of the two values at 8 A. M., and subtracting each hourly value from the mean of the whole (29°.11), we obtain the diurnal variation as given in the following table; the values are given in minutes. For comparison I have added the diurnal variation observed at Van Rensselaer Harbor by Dr. Kane;[1] these results are given in two columns, the second one containing the variation after the omission of the larger disturbances. To separate in our series the disturbances from the regular readings would not lead to any satisfactory results, as the observations are much too limited in number; no very large disturbances, however, are recorded, so that we may with equal advantage compare the Port Foulke results with others, including or excluding the larger disturbances. By the additional comparisons with Point Barrow,[2] Toronto, and Philadelphia,[3] we may be enabled to generalize certain features in the diurnal variation of the north-magnetic hemisphere. Van Rensselaer and Port Foulke are stations situated to the *northward* of the magnetic pole (of dip 90° and horizontal force 0).

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[1] See my discussion of Dr. Kane's Magnetic Observations in the Arctic Seas, in the Smithsonian Contributions to Knowledge, November, 1858.

[2] Phil. Trans. Royal Society, 1857, Part II, Art. xxiv. On hourly observations of the magnetic declination made by Captain R. Maguire, R. N., and the officers of H. M. S. Plover, in 1852–53–54, at Point Barrow. By Maj.-Gen. E. Sabine.

The comparison with Toronto is taken from the same paper.

[3] Smithsonian Contributions to Knowledge, June, 1862. Discussion of the Magnetic and Meteorological Observations made at the Girard College, Philadelphia, 1840 to 1845, Part II. By A. D. Bache, LL.D.

Comparative Table of Diurnal Variation of the Magnetic Declination observed at some stations situated to the northward, southward, eastward and westward of the Magnetic Pole.

West deflection from the normal position is indicated by a + sign, east deflection by a — sign. West elongations are indicated by a × affixed, east elongations by the sign ‡.

Mean local time.	Port Foulke. December to March, 1860–61.	Van Rensselaer Harbor. January to March, 1854.	Van Rensselaer Harbor. Same, omitting large disturbances.	Point Barrow. Omitting larger disturbances, 1852–54.	Toronto. Omitting larger disturbances.	Philadelphia. Winter months, 1841–45.	Philadelphia. Same, omitting large disturbances.
Midnight	—19′‡	—28′	—35′‡	+ 5′.3	—0′.6	—0′.6	—0′.4
1 A. M.	—16	—28	—27	+ 2.8	—0.5	—0.3	—0.3
2 "	—14	—29‡	—35‡	— 0.6	—0.5	—0.3	—0.3
3 "	—19‡	—28	—34	— 4.4	—0.7	—0.4	—0.4
4 "	—12	—28	—26	— 9.0	—1.1	—0.5	—0.5
5 "	—11	—23	—20	—11.4	—1.9	—0.6	—0.7
6 "	— 6	—10	— 8	—14.6	—3.0	—0.9	—1.1
7 "	— 2	+ 1	+ 9	—15.2‡	—4.0	—1.5	—1.7
8 "	+ 7	+12	+19	—12.7	—4.4‡	—2.0‡	—2.2‡
9 "	+14	+17	+23	— 8.2	—3.6	—2.0	—2.2
10 "	+18	+31	+30	— 3.8	—1.2	—1.0	—1.1
11 "	+15	+30	+29	+ 1.4	+1.7	+0.7	+0.6
Noon	+19	+38×	+29	+ 4.8	+4.0	+2.3	+2.2
1 P. M.	+23×	+35	+34×	+ 8.2×	+5.1×	+3.2×	+3.1×
2 "	+22	+26	+26	+ 7.5	+4.9	+3.2	+3.1
3 "	+17	+21	+14	+ 7.2	+3.8	+2.5	+2.4
4 "	+12	+ 7	+ 7	+ 7.2	+2.5	+1.6	+1.5
5 "	+ 7	+24	+24	+ 7.0	+1.3	+0.8	+0.8
6 "	+ 2	+12	+ 6	+ 6.7	+0.5	+0.4	+0.4
7 "	— 5	— 3	— 4	+ 4.4	—0.1	—0.3	—0.1
8 "	— 9	—13	— 9	+ 3.8	—0.2	—1.0	—0.5
9 "	—13	—21	—16	+ 3.9	—0.5	—1.4	—0.9
10 "	—15	—21	—13	+ 4.4	—0.7	—1.4	—0.9
11 "	—14	—22	—22	+ 5.2	—0.7	—1.0	—0.7
	Northward and Eastward.			Westward.	Southward of magnetic pole.		

The geographical position and declination of these stations are as follows:—

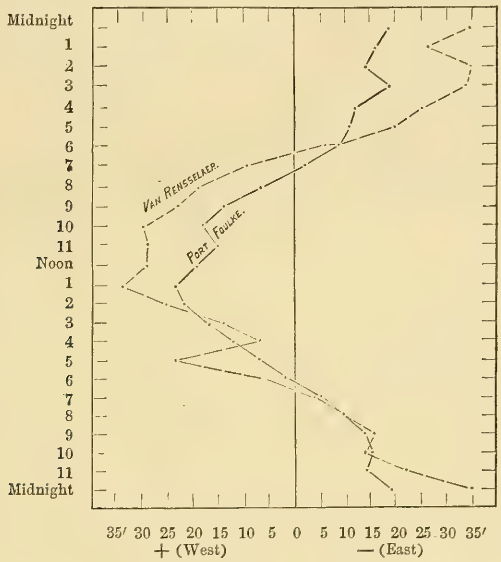
Port Foulke . .	$\phi = 78°$ 18′	$\lambda = 73°$ 00′	D=111° 40′ W.	1861.5	
Van Rensselaer .	78 37	70 53	108 12 W.	1854.5	
Point Barrow . .	71 21	156 15	41 E.	1852–53–54	
Toronto	43 40	79 22	1 45 W.	1853.5	Third Vol. of Toronto Obs. Lond., 1857.
Philadelphia . .	39 58	75 10	3 32 W.	1841–1845	Part XII of Discussion of Gir. Col. Mag. (May, 1864).
Magnetic pole according to Ross	70 05	96 46	- - - - - - -	observed 1831	Phil. Trans., 1834, Vol. I, Art. III.
Magnetic pole according to Evans	70 00	97 00	- - - - - - -	constructed 1858	Map of isogonic lines.

Comparing the Port Foulke and Van Rensselaer Harbor diurnal progression, we notice a close correspondence, viz: a maximum *west* deflection about 1 P. M.; a maximum *east* deflection between 2 and 3 A. M.; a normal position of the needle about 6½ P. M. and 7 A. M.; in fact the only noticeable difference is a less range

of motion at Port Foulke (42′) when compared with that of Van Rensselaer (69′); this may be due to the short series of observations at either place, and partly also to disturbances. The horizontal force at Port Foulke being smaller than at Van Rensselaer, and the former station having been occupied during a maximum of the ten or eleven year inequality, the latter during a minimum of that cycle, we should have expected the greater range at Port Foulke.

The two diurnal curves are further illustrated by means of the accompanying diagram.

Diurnal Variation in Winter.



Comparing the diurnal progression of the several stations, we find them to exhibit the maximum west deflection about 1 P. M., which, I believe, holds good for all places in the north magnetic hemisphere. It has also lately been observed, quite close to the magnetic pole, by Sir Francis L. McClintock[1] at Port Kennedy, in latitude 72° 01′, and in longitude 94° 19′ west, magnetic declination 135° 47′ west (1858–59). At the Whalefish Islands (Boat Island $\phi = 68° 59'$, $\lambda = 53° 13'$) near Godhaven, Lieut. Foster[2] found, in June, 1824, the maximum west deflection about $1\frac{1}{4}$ P. M. The morning maximum east deflection appears to be subject to certain fluctuations, but it keeps within the limits of midnight and 9 A. M.; its epochal variation is mostly due to the interferences of the disturbances which, for

[1] Phil. Trans. Roy. Soc., 1863, Part II. Results of hourly observations of the magnetic declination made by Sir Francis L. McClintock and the officers of the yacht "Fox," at Port Kennedy, in the Arctic Sea in the winter of 1858–59, etc. By Maj.-Gen. E. Sabine.

[2] Phil. Trans. Roy. Soc. 1826, Part IV. Observations on the diurnal variation of the magnetic needle at the Whalefish Islands, by Lieut. H. Foster, June, 1824.

stations near the pole, may reach magnitudes sufficient even to overpower the regular solar diurnal progression.

It will be observed that at Port Foulke the motion of the north end of the needle from early morning till about one hour after noon, is westerly, magnetically, though in reality it is easterly, as the needle points *south* of west.

For the sake of illustration we will suppose an observer stationed at the magnetic pole near King William Island, and two needles placed in his meridian, one north the other south of him, also two needles placed in his parallel, one east the other west; these needles will point with their north or marked end towards him when in their normal position (which, for instance, always happens some hours before noon), but early in the morning, upon turning successively to them he will find them all deviating to his left, and an hour or two after noon he will find them deflected to his right; they have all moved in the interval from left to right, though in reality the marked end of the northern needle moved from west to east, that of the southern needle from east to west, and that of the eastern from north to south, and of the western from south to north; however, the motion of the eastern needle appears earlier, and that of the western later, by the amount of their difference of longitude with that of the observers, the motion being governed everywhere by local solar time.

The declinometer was also observed nearly every day at 8 A. M. and 2 and 10 P. M., between November 12, 1860, and March 9, 1861. There are, however, several interruptions, and the instrument has been moved in the interval. The only use I propose to make of this series is to ascertain the angular motion of the magnet between 2 and 10 P. M., and to form from it an estimate of the diurnal range.

Declinometer Record at Port Foulke. Scale Readings.

1860.	2 P. M.	10 P.M.	1860.	2 P. M.	10 P.M.	1860.	2 P. M.	10 P.M.	1861.	2 P. M.	10 P.M
Nov. 12	38.8	40.0	Dec. 21	33.5	36.3	Jan. 16	28.5	35.8	Feb. 10	29.3	46.0
13	39.2	40.5	22	33.4	35.8	Circle	28° 0′	27° 0′	11	35.8	39.7
14	37.2	43.2	23	34.1	38.0	17	32.1	34.6	12	30.7	42.1
15	37.8	46.2	24	43.0	29.9	18	33.8	36.5	13	36.9	39.3
16	39.0	42.9	Circle	25° 20′	28° 00′	19	33.7	35.2	14	35.9	39.7
17	36.4	44.1	25	18.0	29.4	20	28.4	34.6	15	31.8	38.9
18	41.5	42.0	26	26.1	29.3	21	32.4	35.2	16	31.9	39.7
22	42.0	42.4	27	25.1	29.4	22	39.9	35.5	17	34.2	29.8
23	37.2	46.5	28	25.4	29.7	Circle	23° 0′	27° 0′	18	30.1	37.4
24	43.1	46.5	29	28.8	28.7	23	25.0	36.7	19	35.8	37.1
25	27.9	36.5	30	28.4	29.2	24	14.8	37.5	20	36.3	36.7
Dec. 1	43.3	44.3	31	26.0	28.7	25	11.3	39.9	21	26.7	35.1
3	25.9	27.5	1861			26	17.3	39.0	22	33.8	41.3
4	26.2	27.7	Jan. 2	26.1	34.2	27	28.0	35.9	23	29.8	38.9
5	24.7	27.4	3	28.4	30.8	28	31.6	35.0	24	33.2	39.2
9	33.2	38.3	4	22.7	30.3	29	33.2	37.4	25	38.3	38.7
10	25.6	42.1	5	27.1	30.6	30	34.1	34.9	26	38.5	38.7
11	34.6	36.0	6	15.2	29.0	31	33.6	37.0	27	27.8	38.9
12	35.5	35.7	7	28.0	30.8	Feb. 1	32.8	29.5	28	26.6	38.5
13	35.6	35.7	8	28.5	29.3	2	28.4	36.0	March 1	30.0	24.6
14	34.0	35.6	9	28.7	30.8	3	33.1	35.4	2	35.5	29.9
15	35.6	24.4	10	29.0	29.6	4	30.1	36.0	3	36.9	38.6
16	25.1	35.8	11	27.7	30.8	5	32.4	35.0	4	35.1	39.2
17	34.0	34.3	12	26.3	28.5	6	33.0	35.3	5	38.3	38.9
18	33.3	36.9	13	28.6	29.8	7	34.4	35.6	6	37.6	39.8
19	31.7	38.8	14	24.1	30.2	8	34.3	34.7	7	36.1	39.2
20	30.5	36.2	15	28.6	29.3	9	34.5	34.9	8	38.5	39.0

In the above record I have given the circle reading in those cases only when the circle had been shifted between the two hours of record, its reading from day to day being otherwise of no consequence. If we take the difference each day of the tabular numbers, we find, from 104 days, the average difference 4.42 divisions, or 45′, by which quantity the north end of the needle moved easterly between 2 and 10 P. M. By the preceding diurnal curve we must add 1′ before 2 P. M., and add 4′ after 10 P. M. in order to get to the extreme range, which is therefore 50′, a value preferable to that given before.

At Philadelphia the ratio of the diurnal range in winter, to that of the whole year, is as 5.6 to 7.9, hence applying the same ratio to Port Foulke, we find the probable diurnal amplitude of the declination, on the average throughout the year and for an epoch of its greatest value in the ten or eleven year cycle, to be 1° 10′.

ABSOLUTE DETERMINATIONS.

Observations and Results of Magnetic Declinations.

The declination observations made in connection with the survey of the west coast of Smith Sound and Kennedy Channel, in the spring of 1861, will be given first, next those observed in Smith Strait, and last those determined in North Greenland. There are 14 stations in all.

An approximate correction for diurnal variation was applied to refer the observed declination to the mean declination of the day; this correction was derived from the mean diurnal progression as found at Port Foulke and Van Rensselaer Harbor.

Cairn Point, SMITH STRAIT.

Observations of magnetic declination, April 9, 1861. S. J. McCormick, observer.

Double altitudes and bearing of the sun.

Sextant: 2 ⊙			
	25° 14′	Latitude, $\phi = 68° 30'.8$	$\cos t = \dfrac{\sin h - \sin\phi \sin\delta}{\cos\phi \cos\delta}$
	25 02	Longitude, $\lambda = 4^h 51^m 56^s$	
	24 53		
Mean,	25 03	⊙'s decl'n, $\delta = 7° 49' 15''$	Put $tg\, M = \dfrac{tg\,\delta}{\cos t}$
Index correction,	+ 1	Hour angle, $t = 4^h 15^m 14^s$	
	12 32		then $\cos A = \dfrac{tg\, h}{cotg\,(\phi - M)}$
Refraction—par.,	— 4	$M = 17° 17' 11''$	
Semi-diameter,	+ 16	Azimuth, A = 65° 42′	
Observed altitude, h.	12 44	⊙ Mag. bearing S. 176 00 W.	
		Mag. decl'n, + 110 08 at $4\frac{1}{2}^h$	

Observation of magnetic declination, April 12, 1861. S. J. McCormick, observer.

Bearing of the sun at noon . . . . . . N. 70° W.
Hence magnetic declination . . . . . + 110° 0′

Observations of Magnetic declination, April 15, 1861. I. I. Hayes, observer.

Bearing of the sun.

(Pock.) chron'r correction ΔT April 15	-7^m		51^s	Put $tgM = \frac{tg\,\delta}{cos\,t}$
Observed time of ⏀	11^h	15	00	
Mean time of observation (14th) . .	23	07	09	then $tgA = \frac{tg\,t\;cos\,M}{sin\,(\varphi - M)}$
Equation of time E		+1	13	
Hour angle t	-0	51	38	

$\delta = +\;9°\;55'\;25''$

$M = \;10\;\;10\;\;34$

$A = -\;13\;\;38$

⏀ Magnetic bearing, 262 15 (By Würdmann's compass, counting from S. through E.)

Magnetic decl'n, + 111 23

RECAPITULATION OF RESULTS.

1861.	Observed declination.	Time.	Approximate correction for diurnal variation.	Dec'n.
April 9	+ 110° 18′	$4\frac{1}{4}$ P. M.	—25′	+ 109° 53′
" 12	+ 110 00	Noon	—28	+ 109 32
" 15	+ 111 23	11 A. M.	—22	+ 111 01
			Mean . . .	+ 110 09

Foggy Camp, SMITH SOUND.

Observations for magnetic declination, May 13 (P. M.) 1861. I. I. Hayes, observer.

Bearing of the sun.[1]

P. chron'r $\Delta T = +\,1^h\,19^m\,48^s$				$\varphi = 79°\,55'.5$
Observed time |⊙	4	17	20	$\lambda = 4^h\,45^m\,52^s$
Mean time of ob's,	5	37	08	
E +		3	53	⊙'s $\delta = 18°\,33'\,25''$
t	5	41	01	$M = 76\;\;09.3$
				$A = 88\;\;41.6$
Magnetic bearing |⊙ — 16′				164 14.0

Magnetic declination, + 107 04.4 or + 106° 53′ when corrected for diurnal var'n.

Camp Hawks, SMITH SOUND.

(Two miles from Irving Island, Dobbin Bay.)

Observations for magnetic declination, May 22 (P. M.) 1861. I. I. Hayes, observer.

Bearing of the sun.[2]

P. chron'r $\Delta T = +\,1^h\,14^m\,32^s$				$\varphi = 79°\,43'.7$
Observed time ⏀	8	02	50	$\lambda = 4^h\,52^m\,24^s$
Mean time of ob's,	9	17	22	
E		+3	34	⊙'s $\delta = 20°\,33'\,15''$
t	9	20	56	$M = -26\;\;00.2$
				$A = 142\;\;09\,0$
Magnetic bearing ⏀				102 30.0

Magnetic declination, + 115 21.0 or + 115° 38′ when corrected for diurnal var'n.

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[1] Another observation ⊙\| 168° 25′ at $4^h\,15^m\,58^s$ has been rejected.

[2] Of the following observation I have made no further use: At $7^h\,28^m\,45^s$ angle between sun ⏀ and East Cape, Irving Island, 76° 8′, magnetic bearing of Cape 43° 15′. Computing from these data we have azimuth of Cape 30° 10′ east of north, and magnetic declination + 106° 35′.

Cache, on old Floe, Smith Sound.

Observations for magnetic declination, May 23 (A. M.) 1861. I. I. Hayes, observer.

Bearings of the sun.[1]

Pocket chronometer, May 30, Port Foulke, $\Delta T =$	$+$	$1^h\ 12^m\ 17^s$
$\delta T = -2^s.5$,	$+$	17
May 23, Port Foulke, $\Delta T =$	$+$	1 12 34
Difference of longitude,	$+$	28
ΔT Cache,	$+$	1 13 02

At	$9^h\ 56^m\ 30^s$	sun ⏀ bears	65° 22′	$\phi = 79°\ 30'$
"	10 13 27	" "	75 30	$\lambda = 4^h\ 51^m\ 32^s$
"	10 15 07	" "	76 35	
"	10 19 06	" "	76 15	$\delta_1 = 20°\ 45'\ 27''$
Mean	10 15 53	" "	76 07	$\delta_{11} = 20\ 45\ 37$

P. chron'r, ΔT	$+ 1^h\ 13^m\ 02^s$	$+ 1^h\ 13^m\ 02^s$	$M_1 = -\ 21°\ 09'\ 55''$	$M_{11} = -\ 20°\ 53'\ 56''$
Observed time,	9 56 30	10 15 53	$A_1 =$ 168 50.3	$A_{11} =$ 173 26.6
Mean time of ob's,	11 09 32	11 28 55	$B_1 =$ 65 22.0	$B_{11} =$ 76 07.0
E	+ 3 29	+ 3 29	Mag. decl'n, = +125 47.7	Mag. decl'n, = +110 26.4
t	11 13 01	11 32 24	Weight 1	Weight 3

Magnetic declination, = + 114° 17′ or 113° 52′ when corrected for diurnal variation.

Scouse Camp, Smith Sound.

Observations for Magnetic declination, May 23 (24th, midnight), 1861. I. I. Hayes, observer.

Bearing of the sun.

Pocket chronometer ΔT	$+ 1^h\ 13\ 02$	$\phi = 79°\ 29'$
Observed time ⏀	0 40 00	$\lambda = 4^h\ 51^m\ 32^s$
Mean time of obser'n (23d),	13 53 02	$\delta =$ 20° 46′ 42
E	+ 3 29	$M = -23$ 28.7
t	13 56 31	$A =$ 207 40.5
Magnetic bearing of ⏀		40 35.0
Magnetic declination,		+ 111 44.5 or + 112° 06′ wnen cor'd for diur'l var'n.

Potato Camp, Smith Sound.

Observations for magnetic declination, May 24 (P. M.), 1861. I. I. Hayes, observer.

Bearing of the sun.

P. chr. May 30, Port Foulke $\Delta T =$	$+ 1^h\ 12^m\ 17^s$	$\phi =$	79° 04
$\delta T = -2^s.5$	+ 14	$\lambda =$	$4^h\ 50^m$
May 24, Port Foulke ΔT	+ 1 12 31		
Difference of longitude,	+ 2 00	$\delta =$	20° 54′ 57″
ΔT Potato Camp,	+ 1 14 31	$M =$	— 39 9.8
Observed time ⏀	6 34 00	$A =$	121 07.4
Mean time of observation,	7 48 31	⏀ mag.	133 30.0
E	+ 3 25	Mag. decl'n,	+ 105 23 or 105° 34′ when corrected for diur'l var'n.
t	7 51 56		

[1] An observation at Small berg Camp, on the morning of the same date, was found erroneously recorded, and has therefore been omitted.

Camp Separation, Smith Sound.

Observations for magnetic declination, May 24 (25th A. M.), 1861. I. I. Hayes, observer.

Bearing of the sun.

P. chr. May 25, Port Foulke $\Delta T =$	$+ 1^h$	12^m	30^s	$\phi =$ 78° 53′
Difference of longitude,	+	3	32	$\lambda =$ 4^h $48\frac{1}{2}^m$
T Camp Separation,	+ 1	16	02	
Observed time,	12	58	00	$\delta =$ 20° 57′ 45″
Mean time of obs'tion (24th),	14	14	02	$M =$ — 24 53.6
E	+	3	24	$A =$ 212 33
	14	17	26	Bearing ⏀ 42 45

Magnetic declination, + 104 42 or + 105° 04′ when corrected for diurnal variation.

Last Camp, Smith Sound.

Observations for magnetic declination, May 26 (P. M.), 1861. I. I. Hayes, observer.

Bearing of the sun.

P. chr. May 26, Port Foulke, $\Delta T =$	$+ 1^h$	12^m	26^s	$\phi =$ 78° 38′
Difference of longitude,	+	3	32	$\lambda =$ 4^h $48\frac{1}{2}^m$
ΔT Last Camp,	+ 1	15	58	
Observed time ⏀	5	47	30	$\delta =$ 21° 15′ 36″
Mean time of observation,	7	03	28	$M =$ — 53 36.7
E	+	3	13	$A =$ 110 28.8
	7	06	41	Mag. bearing ⏀ 141 00

Magnetic declination, + 108 31 or + 108° 36′ when corrected for diurnal var'n.

Starr Island, Port Foulke, Smith Strait.

October 27, 1860. August Sonntag, observer.

By means of the observed bearing of the base line and the agreement of the observed and computed latitude of Cape Isabella (see astronomical part) we have the magnetic declination + 109° 45′

$\phi =$ 78° 17′.8 $\lambda =$ 73° 06′.0

Northumberland Island, off south side, Whale Sound. August 3, 1861.

The record of this observation not being quite complete, the observer's result, or + 106° 00′, is adopted.

$\phi =$ 77° 11′ $\lambda =$ 72° 20′

Netlik, Whale Sound.

(For result by declinometer see further on.)

Observations of magnetic declination, August 4 (5th A. M.), 1861. S. J. McCormick, observer.

Bearing of the sun.

Observed time, pocket chronometer,	2^h	20^m	44^s		
Chronometer correction ΔT	—4	41	54	ϕ =	77° 07′.8
Mean time of observation (4th),	21	38	50	γ =	$4^h\ 45^m\ 28^s$
Equation of time E	—	5	41	δ =	16° 54′ 21″
Hour angle t	—2	26	51	M=	20 45.8
				A =	—39 57

ϕ magnetic bearing, S. 68 00 W.

Magnetic declination, + 107 57 or + 107° 37′ when corrected for diurnal variation.

For a second determination see further on.

Port Foulke, Smith Strait, July, 1861.

Observations for magnetic declination at the Observatory. H. G. Radcliff, observer.

Instruments used: Portable declinometer and theodolite.

Observations for azimuth of marks B and C. July 9 P. M., 1861.

The horizontal circle of the theodolite reads in a direction from south towards east.

Bearings of the sun.							
Mark or Limb.	Pocket chronometer.	Circle readings.		Mark or Limb.	Pocket chronometer.	Circle readings.	
$\odot\vert$	$6^h\ 03^m\ 39^s.5$	56° 56′.5	57′.5				
$\vert\odot$	6 06 45.0	57 18	19				
B		40 00	02	$\odot\vert$	$6^h\ 31^m\ 55^s$	49° 31′	31′.5
B		40 00	02	$\vert\odot$	32 45	49 56	55
C		167 25	24.5	B		40 05	05
$\odot\vert$	6 22 38	52 00	01.5	C		167 28.5	26.5
$\vert\odot$	6 24 07	52 14.5	15.5	$\odot\vert$	6 43 20	46 20.5	20
B		40 00.5	02	$\vert\odot$	6 44 36	46 37.0	36.5
C		167 24	24				

We have from the astronomical paper the chronometer correction of 2007 on mean time, July 9, 1861 = — $4^h\ 47^m\ 17^s$, and from the chronometer comparison, pocket chronometer, $2^h\ 03^m\ 35^s.8 = 2^h\ 3^m$ by chronometer 2007; hence $\Delta T =$ —$4^h\ 47^m\ 53^s$; we have also the observed times of the sun's centre, from the above: $6^h\ 05^m\ 12^s$, $6^h\ 23^m\ 22^s$, $6^h\ 32^m\ 20^s$, and $6^h\ 43^m\ 58^s$ by chronometer. The corresponding derived hour angles are $1^h\ 12^m\ 25^s$, $1^h\ 30^m\ 35^s$, $1^h\ 39^m\ 32^s$, and $1^h\ 51^m\ 10^s$, and the computed azimuths, 20° 08′.3, 25° 08′.5, 27° 35′.8, and 30° 46′.5 (all west of south); hence by means of the corresponding circle readings 57° 07′.7, 52° 07′.9, 49° 43′.4, and 46° 28.′5, in connection with the mean reading of B 40° 01′.6, and of C 167° 25′.4 we obtain the

Azimuth of B.	Azimuth of C.
37° 14′.9	37° 15′.2 azimuth of B
37 14.8	127 23.8 angular difference
37 17.6	90 08.6 E. of S.
37 13.4	
Mean, 37 15 2 W. of S.	

SET 1. OBSERVATIONS FOR DECLINATION. July 10, 1861.

The horizontal circle of the declinometer reads in the direction from south towards west. The pointing is upon the axis of the collimator.

Between 2^h and 3^h by chronometer, the collimator magnet read 134° 56′ 20″ and 134° 57′ 00″, and the azimuth mark B 284° 26′ 30″ and 26′ 30″, also C 156° 26′ 00″ and 26′ 40″. We have consequently at $9\frac{3}{4}^h$ A. M.

180° + collimator,	314°	56′.7		314°	56′.7
Mark B,	284	26.5	C,	156	26.3
	30	30.2		158	30.4
Azimuth of B, W. of N.	142	44.8	Azimuth of C,	270	08.6
Magnetic declination W.	112	14.6		111	38.2
			Mean, =	+ 111	56

SET 2. OBSERVATIONS FOR DECLINATION. July 11, 1861.

Between 8^h 35^m and 9^h 35^m by chronometer, the collimator magnet read 134° 56′ 0″ and 56′ 40″, and the azimuth mark B 284° 26′ 10″ and 26′ 40″, also C 156° 26′ 40″ and 26′ 40″. Hence for $4\frac{1}{4}^h$ P. M.

180° + collimator,	314°	56′.3		314°	56′.3
Mark B,	284	26.4	C,	156	26.7
	30	29.9		158	29.6
Azimuth B,	142	44.8	Azimuth C,	270	08.6
Magnetic declination W.	112	14.9		111	39.0
			Mean, =	+ 111	57

Correction for diurnal variation to set 1, — 22′, and to set 2, — 12′, hence corrected mean + 111° 40′.

Netlik, WHALE SOUND.

Observations with portable declinometer and theodolite. H. G. Radcliff, observer.
Observations for azimuth of mark A. August 4, P. M. 1861.

Bearings of the sun.							
Mark or Limb.	Pocket chronometer.	Circle.		Mark or Limb.	Pocket chronometer.	Circle.	
A		8° 34′	36′	⊙|	48^m 28^s	70° 50′	51′
⊙|	10^h 44^m 45^s	71 43	43	|⊙	50 41	70 50	51
|⊙	47 01	71 43	43	A		8 34	36

From the astronomical paper we have, for August 4 (P. M.), the pocket chronometer correction $\Delta T = - 4^h\ 41^m\ 54^s$.

Observed times of the sun's centre 10^h 45^m 53^s and 10^h 49^m 35^s by chronometer. The corresponding computed hour angles are 5^h 58^m 14^s and 6^h 01^m 57^s, and the azimuths 93° 29′.2 and 94° 23′.3 (west of south); hence by means of the corresponding circle readings 71° 43′.0 and 70° 50′.5 in connection with the mean reading of the mark A 8° 35′ we obtain the azimuth of the mark.

156°	37′.2
156	38.8
156	38.0 W. of S.

OBSERVATION FOR DECLINATION. August 4 P. M.

Between 10^h 35^m and 11^h 25^m by chronometer, the collimator magnet read 10° 37′ 00″ and 37′ 40″, and the azimuth mark 273° 42′ 20″ and 43′ 40″. We have—

180° + collimator,	190° 37′.3
Mark A,	273 43.0
	276 54.3
Azimuth of mark W. of N.	23 22.0
Magnetic declination W.	106 27.7 at $6\frac{1}{4}$ P. M. or + 106° 25′ when corrected for diur'l var'n.

Combining this result with the first obtained by S. J. M'Cormick, and giving the weight 2 to Radcliff's determination, and the weight 1 to M'Cormick's, we find the resulting declination + 106° 49′.

Upernavik, NORTH GREENLAND. August 16 P. M., 1861.

Observations with portable declinometer and theodolite. H. G. Radcliff, observer.

Observations for azimuth of mark A.

Bearings of the sun.							
Mark or Limb.	Pocket chronometer.	Circle.		Mark or Limb.	Pocket chronometer.	Circle.	
A		266° 45′.5	47′	|⊙	10^h 42^m 05^s	145° 15′	14′
A		266 45	46	A		266 47	46
⊙|	10^h 27^m 42^s	148 06	05.5	⊙|	10 31 02	147 18	18
|⊙	10 29 55	148 05.5	05.5	|⊙	10 33 20	147 18	18
A		266 47	46	A		266 45	46
⊙|	10 39 51	145 15.5	14.5				

The astronomical paper furnishes $\Delta T = -3^h\ 41^m\ 52^s$ (sufficiently near for Aug. 16). We have the observed times of the sun's centre 10^h 28^m 48^s, 10^h 32^m 11^s, and 10^h 40^m 58^s, the corresponding computed hour angles 6^h 43^m 01^s, 6^h 46^m 24^s, and 6^h 55^m 11^s, also the computed azimuths of the sun 75° 44′.8, 74° 57′.0, and 72° 53′.0 (W. of N.); the corresponding circle readings are 148° 05′.6, 147° 18′.0, and 145° 14′.8; the mean reading of the mark A, 266° 46′.2 and its azimuth

$$\left.\begin{array}{l}14^\circ\ 25'.4\\ 14\ \ 25.2\\ 14\ \ 24.4\end{array}\right\}\ \text{Mean } 14^\circ\ 25'.0 \text{ E. of S.}$$

OBSERVATIONS FOR DECLINATION. August 17, A. M., 1861.

Between 2^h 0^m and 3^h 0^m by chronometer, the collimater magnet read 161° 13′ 30″ and 14′ 00″, and the azimuth mark A 219° 21′ 30″ and 22′ 00″; we find

180 + collimator,	341° 13′.7
Mark A,	219 21.7
	121 52.0
Azimuth of mark W. of N.	194 25.0
Magnetic declination W.	72 33.0 at 10^h 50^m A. M., correction for diurnal variation —21′.

A result which appears to me rather doubtful, though not differing more than $2\frac{1}{2}$° from Captain Inglefield's determination in 1854, which was 75° W. The

diurnal variation and the disturbances in these high latitudes comprise so large a range as to require many and continued observations of the magnet. The result of the following observations, taken by Mr. Sonntag, at Pröven, accords well enough with the supposed distribution of magnetism as marked upon the Admiralty Chart of Baffin Bay of 1859 (No. 2177).

Pröven, North Greenland. August 8 (P. M.) 1860.
Instrument used: the theodolite. Observer, A. Sonntag.
Bearings of the sun.

Limb.	Pocket chronometer.	Circle.		Magnetic meridian.
⊙|	$1^h\ 20^m\ 21^s$	29° 29′	30′	332° 02′
|⊙	1 21 24	29 49	50	03
|⊙	1 22 10	29 36	37	03
⊙|	1 22 50	28 50	50	02
|⊙	1 26 51	28 30	31	
⊙|	1 27 46	27 40	41	152 36.6
⊙|	1 28 35	27 26	27	35.6
|⊙	1 29 40	27 45	46	

We have from the astronomical paper the correction of the pocket chronometer, August 8, 1860, $\Delta T = +\ 1^h\ 01^m\ 38^s$; the latitude $\phi = 72°\ 23'\ 01''$, and the longitude $\lambda = 3^h\ 42^m\ 11^s.1$. We find the hour angles $2^h\ 18^m\ 01^s$ and $2^h\ 24^m\ 33^s$ for the two sets, and the corresponding azimuths of the sun 39° 01′.5 and 40° 48′.0.

Magnetic meridian	152° 19′.3	152° 19′.3
Circle reading	29 26.3	27 50.8
Difference	122 53.0	124 28.5
Azimuth of sun	39 01.5	40 48.0
Magnetic declination W.	83 51.5	83 40.5

Mean declination + 83° 46′ or + 83° 24′ when corrected for diurnal variation.

Recapitulation of observed Declinations.
West (magnetic) declination is indicated by a + sign.

No.	Locality.	Latitude.	Longitude.	Declination.	Date.	Observer.
1	Pröven, North Greenland,	72° 23′	55° 33′	+ 83° 24′	Aug. 1860	A. Sonntag
2	Starr Island, Smith Strait,	78 18	73 06	+109 45	Oct. "	"
3	Cairn Point, "	78 31	72 59	+110 09	Apr. 1861	I. I. Hayes and S. J. M'Cormick
4	Foggy Camp, Smith Sound	79 55	71 28	+106 53	May, "	I. I. Hayes
5	Camp Hawks, "	79 44	73 06	+115 38	" "	"
6	Cache on Floe, "	79 30	72 53	+113 52	" "	"
7	Scouse Camp, "	79 29	72 53	+112 06	" "	"
8	Potato Camp, "	79 04	72 30	+105 34	" "	"
9	Camp Separation, "	78 53	72 08	+105 04	" "	"
10	Last Camp, "	78 38	72 08	+108 36	" "	"
11	Port Foulke, Smith Strait,	78 18	73 00	+111 40	July "	H. G. Radcliff
12	Northumberland Island, Whale Sound,	77 11	72 20	+106 00	Aug. "	- - - - - - -
13	Netlik, "	77 08	71 22	+106 49	" "	H. G. Radcliff & S. J. M'Cormick
14	Upernavik, N. Greenland,	72 47	56 03	+ 72 12	" "	H. G. Radcliff

On the accompanying chart of iso-magnetic lines in the vicinity of Smith Strait, the isogonic lines are shown by full lines; they depend upon eleven observed declinations, those at Camp Separation and Potato Camp were excluded on account of instrumental defect and discordance, and Kane's determination at Van Rensselaer Harbor ($D = 108° 12'$ W., June, 1854, latitude 78° 37′, longitude 70° 53′) was admitted without correction for secular change, which is at present too imperfectly known and is certainly less than the errors to which the observations are liable.

The following simple expression for the distribution of the magnetic declination is sufficient for our case:—

$$D = D_0 + x\Delta\phi + y\Delta\lambda \cos \phi$$

where

D = resulting declination, at adopted epoch in latitude ϕ, longitude λ

D_0 = mean declination at epoch, in mean latitude ϕ_0 and mean longitude λ_0

$\Delta\phi = \phi - \phi_0$ and $\Delta\lambda = \lambda - \lambda_0$

These eleven observations give as many equations of conditions of the form $0 = D_0 - D + x\Delta\phi + y\Delta\lambda \cos \phi$ from which x and y can be eliminated by the ordinary process.

We find $D_0 = +109°.97$ $\phi_0 = 78°.67$ $\lambda_0 = 72°.37$

and $D = +109°.97 + 1.61\ \Delta\phi + 14.65\ \Delta\lambda \cos \phi$

by means of which equation the isogonic lines for 105°, 110°, and 115° have been located on the chart; the epoch is 1861.

The observations are represented as follows:—

	Observed D.	Computed D.	Difference.
Starr Island	+109°.75	+111°.57	—1°.82
Cairn Point	+110.15	+111.49	—1.34
Foggy Camp	+106.88	+109.64	—2.76
Camp Hawks	+115.63	+113.29	+2.34
Cache on Floe	+113.88	+112.63	+1.25
Scouse Camp	+112.10	+112.59	—0.49
Last Camp	+108.60	+109.18	—0.58
Port Foulke	+111.67	+111.27	+0.40
Northumberland Island	+106.00	+107.42	—1.42
Netlik	+106.82	+104.27	+2.55
Van Rensselaer Harbor	+108.20	+105.64	+2.56

Probable error of any single determination $\pm 1°.3$, and of any resulting line on chart $\pm 0°.4$ nearly. These lines, when prolonged in one direction, must necessarily pass through the geographical pole, and in the other they extend to the magnetic pole.

MAGNETIC INTENSITIES.

Observations and Results.

WASHINGTON, D. C., June, 1862.

The following observations were made by myself at Washington, D. C., for the purpose of determining certain instrumental constants required for the reduction of the intensity observations made by the expedition.

The instrument was received here in May, 1862; it had not been used since its return from Greenland.

Determination of Moment of Inertia of Ring C.

Dimensions: Outer diameter, 2.335 inches } Temperature, 81° Fah.
Inner " 1.812 "
Weight, 572.62 grains

Moment of inertia $K_1 = \frac{1}{2}(r^2 + r_1^2)\, w$. Where r and r_1 (in feet) equal outer and inner radius and w the weight, we find

$\log k_1 = 0.63771$ at 81° Fah.
$\log k_1 = 0.63775$ at 85 "

the linear expansion being 0.0000105 parts for each degree; the thickness of the ring is 0.147 inch; it is of bronze.

Determination of Moment of Inertia of Magnet Z 6 and its Appendages.

Station, Coast Survey Office, Washington, D. C., June 13, 1862. Determination of value of one division of scale on telescope.

Azimuth circle.		Scale divisions.		
5° 17′ 20″	18′ 20″	300.8	295.2	Forming the differences we have
9 16 20	17 00	59.5	64.1	17° 22′ 45″ = 1028.8 divisions or
0 33 40	34 40	579.0	575.5	1 division = 1′.014
5 15 10	16 00	301.7	298.4	

The azimuth circle reads in the direction from S. towards W., and an increase of scale reading (on telescope) corresponds to an east movement of the north end of the magnet.

Change of magnetic moment of deflecting magnet (Z 6) for 1° of temperature, $q = 0.0002$.

EXPERIMENTS OF VIBRATION. SET 1.

Magnet Z 6 suspended. Chronometer Kessels 1247, fast of mean time $2^h\ 32^m$, gains daily 6^s.
Charles A. Schott, observer.

No. of vibrations.	Time.	Temperature.	Extreme scale readings.	300 vib'ns at 84°.0.
0	$2^h\ 37^m\ 49^s.0$	85° Fah	359 and 241	
20	38 57.7			
40	40 06.6			
60	41 16.1			
80	42 24.7			
100	43 33.6			
200	49 18.9			
300	55 03.7			$17^m\ 14^s.7$
320	56 12.6			14.9
340	57 22.0			15.4
360	58 31.0			14.9
380	50 40.1			15.4
400	3 00 49.1	83.0	319 and 277	15.5
			Mean	17 15.13

Coefficient of torsion.

Tors. circle.	Scale.		Differences.
177°	301.6 and 295.2		
			2.6
267	299	303	
			4.5
87	300	293	
			1.4
177	301	294.8	

Mean (of 4) . . . . 2.13 = 2′.15

Observed time of 300 vib'ns,	1035^s.13
Time of one vibration,	3.4504
Correction for rate,	—0.0002
T	3.4502

and when corrected for torsion and referred to temp. 85°, $lg\,T^2 = 1.07597$

EXPERIMENTS OF VIBRATION. *Set 2, with inertia ring.

No. of vibrations.	Time.	Temperature.	Extreme scale readings.	150 vib'ns at 85°.
0	4^h 09^m 22^s.7	86° Fah.	356 and 246	
20	11 36.0			
40	13 49.3			
60	16 03.5			
80	18 16.6			
100	20 30.8			
150	26 04.6			16^m 41^s.9
170	28 17.0			41.0
190	30 31.8			42.5
210	32 45.5			42.0
230	34 59.4			42.8
250	37 12.7	84.0	332.2 and 268	41.9
			Mean . . .	16 42.02

Coefficient of torsion.

Tors. circle.	Scale.		Differences.
177°	298.2 and 302.5		
			3.6
267	303.8	304	
			5.7
87	293.5	303	
			1.8
177	301.0	299	

Mean (4). . . . 2.8 = 2′.83

Observed time of 150 vib'ns,	1002^s.02
Time of one vibration,	6.6801
Correction for rate,	—0.0004
T_1	6.6797

and when corrected for torsion, $lg\,T_1^2 = 1.64975$

EXPERIMENTS OF VIBRATION. Set 3.

No. of vibrations.	Time.	Temperature.	Extreme scale readings.	200 vib'ns at 83°.5.
0	4^h 47^m 07^s.3	83°	252 and 355	
20	48 16.1			
40	49 25.3			
60	50 34.7			
80	51 43.7			
100	52 52.6			
200	58 38.5			11^m 31^s.2
220	59 47.6			31.5
240	5 00 56.6			31.3
26	2 05.5			30.8
280	3 14.7			31.0
300	4 23.9	84	324 and 280.6	31.3

Mean	11 31.18
Observed time of 200 vibrations . . .	691^s.18
Time of one vibration	3.4559
Correction for rate	—0.0002
T	3.4557

And when corrected for torsion and referred to 85° Fah., . . . $lg\,T^2 = 1.07737$

By set 1 we have . . . . $lg\,T^2 = 1.07597$

Mean 1.07667

The relation $K = K_1 \left(\frac{T^2}{T_1^2 - T^2}\right)$ gives lgk—0.19972

We have therefore $lg\ (\pi^2 k) = 1.19402$ for temperature 85° Fah., and taking the coefficient of expansion of steel = 0.0000068 we find also $lg\ (\pi^2 k) = 1.19378$ for temperature 45°.

Determination of Magnetic Moment of Z 6 and of the Horizontal Force.

Experiments of deflection. June 13, 1862. Magnet Z 6 deflecting at right angles to magnet Z 1 suspended. Deflecting distance 1.35 feet.[1]

Circle readings, $11^h\ 0^m$. Temperature, 85°.

Magnet.	North end.	Order.	A.	B.	Order.			
E.	E.	1	7° 34′ 00″	34′ 40″				
	W.				2	1° 3′ 10″	3′ 40″	
	E.	3	7 32 30	33 40				
	W.				4	1 3 00	4 00	
	E.	5	7 33 10	34 10				
		Mean,	7 33.7			1 03.5		$2u = 6°\ 30\ .2$
W.	W.				6	1 3 40	4 10	
	E.	7	7 37 00	38 00				
	W.				8	1 3 40	5 00	
	E.	9	7 36 00	36 40				
	W.				10	1 3 40	4 40	
		Mean,	7 36.9			1 04.1		$2u = 6\ \ 32.8$
		At	$11^h\ 32^m$	Temperature, 85°				$u = 3\ \ 15.75$

Line of detorsion, 177°

For the determination of the coefficient P depending upon the distribution of the free magnetism in the magnets, we have seven sets of observations of deflections at distances of 1.0 (in one case of 0.9) and of 1.3 foot. By means of the distances r and r_1 and the corresponding angles of deflection u and u_1 we have

$$P = -\frac{r^2\, r_1^5 \sin u_1 - r_1^2\, r^5 \sin u}{r_1^5 \sin u_1 - r^5 \sin u}$$

The observations themselves will be found in their proper place in this paper.

Locality.	Date.			r feet.	u	r_1 feet.	u_1	P
Cambridge,	1860.	July	3	1.0	9° 39′ 02″	1.3	4° 24′ 15″	—0.0153
Port Foulke,	1861.	July	2	0.9	49 52 36	1.3	14 39 25	+0.0044
"	"	"	7	1.0	34 12 41	1.3	15 13 51	—0.0606
"	"	"	8	1.0	33 58 36	1.3	15 08 08	—0.0607
"	"	"	9	1.0	34 14 04	1.3	15 24 53	—0.0851
Upernavik,	"	August	16	1.0	26 21 26	1.3	11 37 53	+0.0057
Godhavn,	"	September	7	1.0	19 45 38	1.3	8 59 49	—0.0382
						Mean	. .	—0.0357

This large value of P is occasioned by the fact that the two magnets are of equal size.

[1] Correction for defect of wooden Scale + 0.0003 foot.

The horizontal force X, and the magnetic moment m of magnet Z 6[1], are obtained from the formulæ

$$mX = \frac{\pi^2 k}{T^2} \text{ and } \frac{m}{X} = \tfrac{1}{2}\, r^3 \sin u \left(1 - \frac{P}{r^2}\right)$$

[1] In addition to the above observations at Washington, I have made the following with the *magnets exchanged,* from which we obtain an independent result.

EXPERIMENTS OF DEFLECTIONS. June 14, 1862. Magnet Z 1 deflecting at right angles to magnet Z 6 suspended. Deflecting distance 1.3 foot (correction + 0.0003).

The record and order of observations are the same as in the set of deflections given in the text, and are here given in a more condensed form

Set 1. 11h 51m Temp. 86° Fah.

	247° 48′ 20″	50′ 19″	242° 13′ 48″	14′ 25″	$2u = 5° 35' 16''.2$
E. E.	247 49 20	50 30	W. 242 14 10	14 50	
	247 48 40	50 20			
			242 12 00	12 45	
	247 48 25	49 20	W. 242 10 00	10 30	
W. E.	247 47 20	48 20	242 10 00	10 50	$2u = 5\ 37\ 20.3$

Line of detorsion 211° 1h 25m Temp. 90°

Set 2. Distance 1 foot. 1h 40m Temp. 91°

	251° 06′ 10″	06′ 40″	238° 51′ 00″	51′ 20″	$2u = 12° 16' 22''$
E. E.	251 07 00	08 00	W. 238 51 00	51 40	
	251 08 30	09 20			
			238 57 10	57 00	
W. E.	251 12 00	13 00	W. 238 57 00	58 20	$2u = 12\ 15\ 12$
	251 12 59	14 00	238 58 00	59 20	

2h 40m; at temp. 92°

From these deflections we find $P = -0.01365$ and $lg\,\frac{m}{X} = 8.73381$

EXPERIMENTS OF VIBRATION. June 16, 1862.

Magnet Z 1 suspended. Inertia ring C. Chronometer 1287, gains 6s a day.

No. of vib'ns.	Time.	Temp.	Extreme scale readings.	150 vibrations at 71°.
0	5h 17m 52s.0	70°	240	
20	20 23.5		and	
40	22 55.8		365	
60	25 27.0			
80	27 58.8			
100	30 30.3			
150	36 49.0			18m 57s.0
170	39 21.8			58.3
190	41 52.5			56.7
210	44 24.0		265	57.0
230	46 55.8		and	57.0
250	49 27.8	72°	330	57.5
Mean				18 57.25

Observed time of 150 vib'ns,	1137s.25
Time of one vibration,	7.5816
Correction for rate,	—0.0004
	7.5812

and when corrected for torsion and referred to 89°.7 Fah.

$lg\,T_1^2 = 1.76132$

Combining the deflections with the vibrations, we find —

From first set	$X = 4.286$	and $m = 0.3062$ at 85° Fah.
From last set	4.279	0.3057
Mean,	4.283	0.3060

Magnet Z 1 suspended without ring.

No. of vib'ns.	Time.	Temp.	Extreme scale readings.	200 vibrations at 78°.
0	6ʰ 12ᵐ 48ˢ.5	78°	270	
20	14 06.5		and	
40	15 25.0		330	
60	16 43.3			
80	18 01.9			
100	19 19.0			
200	25 50.5			13ᵐ 02ˢ.0
220	27 10.5			04.0
240	28 28.3			03.3
260	29 46.5		286	03.2
280	31 05.0		and	03.1
300	32 23.6	78°	315	04.6
Mean . . .				13 03.37

Observed time of 200 vib'ns, 783ˢ.37
Time of one vibration, 3.9168
Correction for rate, —0.0002

3.9166

and when corrected for torsion and referred to 89°.7 Fah.

$lg\,T^2 = 1.18702$

We find $lgk_1 = 0.63779$ at 89°.7
$lgk = 0.19809$ for Z 1
$lg\,mX = 0.00537$
$X = 4.323$ and $m = 0.2342$ at 89°.7 Fah.; magnet Z 1

To compare the above values for the horizontal force with similar determinations at Washington, I have given a complete table of results, as far as known to me. See U. S. Coast Survey Report of 1861, Appendix N. 22, also Coast Survey Report of 1863. From my observations, in 1858, in connection with Kane's Arctic Expedition, I deduce $X = 4.255$; and for 1862.5 we have the means of the three values given above, or 4.296.

Complete table of horizontal intensities determined at Washington, D. C.

No.	Year.	Observer.	Locality.	X	No.	Year.	Observer.	Locality.	X
1	1842.5	Lefroy	Capitol Grounds	4.347	10	1856.7	Schott	Coast Sur. Office	4.309
2	1844.5	Locke	Georgetown	4.282	11	1856.7	"	Capitol Grounds	4.308
3	1844.5	"	Capitol Grounds	4.313	12	1858.3	"	Coast Sur. Office	4.255
4	1844.5	"	Mag. Obs'y, Cpt.	4.282	13	1859.6	"	" " "	4.307
5	1845.2	Lee	Coast Sur. Office	4.240	14	1860.7	"	" " "	4.319
6	1845.9	"	" " "	4.233	15	1862.5	"	" " "	4.296
7	1851.5	Dean	Georgetown	4.229	16	1862.6	"	" " "	4.296
8	1855.7	Schott	Smithsonian Inst.	4.338	17	1863.6	"	" " "	4.282
9	1855.7	"	Georgetown	4.250					
			Mean . . .			1853.6			4.287
								Mean, omitting Georgetown values,	4.295

These values were determined with different instruments and magnets; the X at Georgetown heights appears to be smaller than the Washington value proper (the two positions are 4 miles apart).

Observations at Cambridge, Mass. July 3, 1860.

Harvard College Observatory. A. Sonntag, observer.

Experiments of vibration. Magnet Z 6 suspended. Time noted by sidereal chronometer Bond 236. Temperature, 76° Fah.

No. of vib'n.	Left to right.	No. of vib'n.	Left to right.	Time of 50 double vibrations.	
0	12h 18m 53s.2	50	12h 25m 09s.7	6m 16s.5	
1	19 00.8	51	17.1	16.3	
2	08.3	52	24.8	16.5	Set 1.
3	15.8	53	32.2	16.4	Time of a double
4	23.2	54	39.7	16.5	vib'n, 7s.5296
5	30.8	55	47.3	16.5	
6	38.2	56	54.8	16.6	
7	45.8	57	26 02.3	16.5	
8	53.3	58	09.8	16.5	
9	20 00.9	59	17.3	16.4	
10	08.2	60	24.8	16.6	
		Mean		6 16.48	

Arc at commencement 150 and 460
" end 180 420

No. of vib'n.	Right to left.	No. of vib'n.	Right to left.	Time of 50 double vibrations.	
0	12h 20m 49s.5	50	12h 27m 06s.3	6m 16s.8	
1	57.2	51	13.8	16.6	
2	21 04.8	52	21.2	16.4	
3	12.3	53	28.8	16.5	Set 2.
4	20.0	54	36.2	16.2	Time of a double
5	27.4	55	43.9	16.5	vibration 7s.5282
6	35.0	56	51.2	16.2	
7	42.5	57	59.0	16.5	
8	50.1	58	28 06.3	16.2	
9	57.7	59	14.0	16.3	
10	22 05.2	60	21.5	16.3	
		Mean		6 16.41	

Arc at commencement 170 and 435
" end 190 410

Time of 2 vibrations,	7.5289
Correction for rate,	—0.0206
(By sets 1 and 2),	7.5083

Experiments of Vibrations, continued. Temperature, 74° Fah.

No. of vibration.	Left to right.	Time of 200 double vibrations.	
200	12h 43m 59s.3	25m 06s.1	
201	44 06.8	06.0	
202	14.4	06.1	
203	22.7	06.9	Set 3.
204	29.2	06.0	Time of a double vibration,
205	36.9	06.1	7s.5309
206	44.3	06.1	
207	51.9	06.1	
208	59.4	06.1	
209	45 07.0	06.1	
210	14.6	06.4	
Arc, 252 and 338		Mean, 25 06.18	

Experiments of Vibrations, continued. Temperature 74° Fah.

No. of vibration.	Right to Left.	Time of 200 double vibrations.	
200	12^h 45^m $56^s.0$	25^m $06^s.5$	
201	46 03.7	06.5	
202	11.1	06.3	
203	18.8	06.5	Set 4.
204	26.2	06.2	Time of a double vibration
205	33.8	06.4	$7^s.5316$
206	41.3	06.3	
207	48.8	06.3	
208	56.2	06.1	
209	04.0	06.3	
210	11.4	06.2	
Arc 250 and 340	Mean,	25 06.33	

Time of 2 vibrations	7.5312	
Correction for rate	—0.0206	
By sets 3 and 4	7.5106	weight 4
By sets 1 and 2	7.5083	weight 1
$2T^1 =$	7.5101	at 74°.4 Fah.
$T^1 =$	3.7550	"

And when corrected for torsion and referred to temperature 72°.75 $lg\,T^2 = 1.14976$.

Observations for Torsion.

Tor. cir.	Scale.		Differences.
69°	298.6 and 308.8		
			6.8
159	308	313	
			17.0
339	235	302	
			10.0
69	295	312	
	Mean (4) . . .		8.45 = 8′.57

Experiments of Deflection. July 3, 1860.

Magnet Z 6 deflecting; Z 1 suspended. Distance 1.0 foot. Temperature, 73°.

Magnet.	Circle reading.		Set 1.	
S. end east	145° 54′ 20″	54′ 40″	145° 50′ 05″	19° 18′ 05″
N. " west	145 45 40	45 40		
S. " "	126 40 40	41 20	126 32 00	9 39 02 $= u$
N. " east	126 23 00	23 00		

Distance 1.3 foot. Temperature, 72°.5.

Magnet.	Circle reading.			
N. end east	131 43 00	43 40	131 46 00	8 48 30
S. " west	131 48 20	49 00		
N. " "	140 34 00	35 00	140 34 30	4 24 15 $= u$
S. " east	140 34 00	35 00		

From $lg\, mX = 0.04019$

and $lg\, \frac{m}{X} = 8.92999$ we find $X = 3.607$[1]

and $m = 0.3070$ at 73°

[1] For comparison the following four values were taken from the Coast Survey Report of 1861, Appendix No. 22. Cambridge $\phi = 42° 23'$ and $\lambda = 71° 07'$

No.	Year.	Observers.	X
1	1842.5	Locke	3.657
2	1842.8	Lefroy	3.665
3	1845.5	Locke	3.618
4	1856.6	Friesach	3.542
5	1860.6	Sonntag	3.607

Pröven, North Greenland, August, 1860.

Magnet Z 1 suspended.[1] A. Sonntag, observer. August 9 P. M.

Set 1. Vibrations. 200 vibrations.

L. to R.	0	$2^h\ 00^m\ 12^s.0$	200	$2^h\ 21^m\ 39^s.8$	$21^m\ 27^s.8$	
R. to L.	1	18.5	201	46.8	28.3	
L. to R.	2	25.0	202	53.0	28.0	
R. to L.	3	31.3	203	59	27.7	
L. to R.	4	37.8	204	22 05.5	27.7	
R. to L.	5	43.8	205	12.8	29.0	
L. to R.	6	50.8	206	18.8	28.0	
R. to L.	7	57.2	207	25.8	28.6	200 vibrations = $1288^s.32$
L. to R.	8	01 03.3	208	32.0	28.7	1 vibration 6.4416
R. to L.	9	09.8	209	38.8	29.0	
L. to R.	10	16.2	210	44.9	28.7	

Arc: 152 and 454 218 and 343 Mean, 21 28.32 at 41° Fah.

Set 2. Vibrations.

L. to R.	30	$2^h\ 03^m\ 24^s.6$	230	$2^h\ 24^m\ 53^s.5$	$21^m\ 28^s.9$	
R. to L.	31	30.8	231	25 02	31.2	
L. to R.	32	37.5	232	06.8	29.3	
R. to L.	33	44.0	233	15.0	31.0	
L. to R.	34	50.2	234	19.8	29.6	200 vibrations = $1290^s.39$
R. to L.	35	56.5	235	27.8	31.3	1 vibration 6.4520
L. to R.	36	04 03.2	236	32.8	29.6	
R. to L.	37	09.2	237	40.8	31.6	
L. to R.	38	15.8	238	45.8	30.0	
R. to L.	39	22.0	239	53.7	31.7	
L. to R.	40	28.9	240	56.0	30.1	

Arc: 180 and 442 222 and 333 Mean, 21 30.39 at 41° Fah.

Set 3. Vibrations.

L. to R.	0	$2^h\ 33^m\ 22^s.2$	200	$2^h\ 54^m\ 55^s.3$	$21^m\ 33^s.1$	
R. to L.	1	29.0	201	55 01.7	32.7	
L. to R.	2	35.6	202	08.0	32.4	
R. to L.	3	41.6	203	14.8	33.2	
L. to R.	4	48.2	204	21.0	32.8	200 vibrations = $1292^s.72$
R. to L.	5	55.1	205	27.4	32.3	1 vibration 6.4636
L. to R.	6	34 01.3	206	34.0	32.7	
R. to L.	7	07.3	207	40.0	32.7	
L. to R.	8	14.2	208	47.0	32.8	
R. to L.	9	20.8	209	53.2	32.4	
L. to R.	10	27.0	210	59.8	32.8	

Arc: 143 and 518 228 and 368 Mean, 21 32.72 at 39° Fah

Set 4. Vibrations.

L. to R.	30	$2^h\ 36^m\ 36^s.7$	230	$2^h\ 58^m\ 08^s.2$	$21^m\ 31^s.5$	
R. to L.	31	42.8	231	15.2	32.4	
L. to R.	32	50	232	21	31.0	
R. to L.	33	56	233	28	32.0	
L. to R.	34	37 03	234	33.8	30.8	200 vibrations = $1291^s.54$
R. to L.	35	09	235	40.8	31.8	1 vibration 6.4577
L. to R.	36	16	236	47	31.0	
R. to L.	37	22	237	53.8	31.8	
L. to R.	38	28	238	59.8	31.8	
R. to L.	39	35	239	59 06.8	31.8	
L. to R.	40	41.8	240	12.8	31.0	

Arc: 158 and 470 228 and 350 Mean, 21 31.54 at 39° Fah.

[1] That Z 1 was suspended is proved also by the resulting X; Z 6 ought to have been suspended.

The mean of four sets gives 1 vibration 6.4537 at 40° Fah. The value of m for Z 1, as determined at Washington at 89°.7, = 0.2342, at 40° it becomes 0.2365; we have also $lg\,(\pi^2 k) = 1.19239$ at 89°.7, and 1.19209 at 40°. Correcting for torsion we find $lg\ mX = 9.57134$ and $X = 1.576$.

Port Foulke, Smith Strait.

Observations at the Port Foulke Observatory.

Set 1. Deflections. $3^h\ 39^m$ P. M., July 2, 1861.

Magnet Z 1 suspended, Z 6 deflecting; distance 1.3 foot.

Magnet.	North end.	Circle.		Temperature.	
E.	E.	38° 52′ 40″	53′ 10″	40°.5	
"	"	38 54 00	54 50		$2u = 28° 51' 02''$
"	W.	10 00 40	01 40		
"	"	10 04 00	04 10	39	
W.	"	9 40 20	41 40		
"	"	9 42 10	43 10		$2u = 29\ 46\ 38$
"	E.	39 29 20	30 10		
"	"	39 26 40	27 40	39.8	
			Mean . . .	39.8	$u = 14\ 39\ 25$

Set 2. Deflections. Distance 0.9 foot. $4^h\ 38^m$.

W.	E.	76 15 20	15 20	39	
"	"	76 17 00	17 00		$2u = 101\ 05\ 58$
"	W.	335 10 30	11 00		
"	"	335 09 20	10 00		
E.	"	338 01 40	02 00	38	
"	"	337 59 30	60 20		$2u = 98\ 24\ 26$
"	E.	76 23 50	24 00		
"	"	76 26 40	26 40	39.2	
			Mean . . .	38.7	$u = 49\ 52\ 36$

Set 3. Deflections. Distance 1.0 foot. A. M. July 7, 1861.

E.	E.	26 44 40	45 00	44.2	
"	"	26 43 20	44 00		$2u = 68\ 24\ 25$
"	W.	318 19 20	20 00		
"	"	318 19 40	20 20	45.0	
W.	"	318 19 40	20 40		
"	"	318 19 40	20 20	43	$2u = 68\ 26\ 20$
"	E.	26 46 20	47 20		
"	"	26 45 20	46 00	43	
			Mean . . .	43.8	$u = 34\ 12\ 41$

Observations for Torsion.

Torsion circle.	Scale.	Differences.	
280° 30′	300		
370 30	311.8	11.8	
190 30	292.0	19.8	Mean (4) = 10.0 = 10′.1
280 30	300.5	8.5	

Set 4. Deflections. Distance 1.3 foot A. M. July 7, 1861.

W.	E.	7° 47′ 00″	47′ 20″	42°	
"	"	7 47 20	47 40		$2u = 30° 27' 15''$
"	W.	337 19 40	20 40	42	
"	"	337 19 20	20 40		
E.	"	337 25 20	26 00	41.6	
"	"	337 25 20	26 00		$2u = 30\ 28\ 10$
"	E.	7 53 20	54 20	41.2	
"	"	7 53 20	54 20	40	
			Mean . . .	41.4	$u = 15\ 13\ 51$

Set 5. Vibrations. July 7, 1861.

Magnet Z 6 suspended. M. T. Pocket chronometer; rate nearly zero. Temperature, 51°.

Number.	Chronometer.	Number.	Chronometer.	300 vibrations.
0	$11^h\ 01^m\ 21^s$	300	$11^h\ 35^m\ 16^s$	$33^m\ 55^s$
10	02 29	310	36 24	33 55
20	03 36	320	37 32	33 56
30	04 44	330	38 40	33 56
40	05 52	340	39 47	33 55
50	06 59	350	40 55	33 56
100	12 38.5	200	23 57	33 55.5

Observed time of 300 vibrations, $2035^s.5$
Time of one, 6.7850

Arc: 204 and 402 at beginning, or 0
294.5 305 at end, or 350 vib's.

Observations for Torsion.

Torsion circle.	Scale.	Differences.
50°	300	
140	320.7	20.7
230	286	34.7
50	300.5	14.5

Mean (4) = 17.5 = 17′.7

Set 6. Vibrations. P. M. July 8, 1861.

Magnet Z 6 suspended on 4 fibres. Temperature, 41°.

Number.	Chronometer.	Number.	Chronometer.	300 vibrations.
0	$1^h\ 13^m\ 03^s$	300	$1^h\ 47^m\ 02^s$	$33^m\ 59^s.0$
10	14 10.5	310	48 09	33 58.5
20	15 18	320	49 17.2	33 59.2
30	16 26	330	50 25	33 59.0
40	17 33.8	340	51 32.8	33 59.0
50	18 42	350	52 40.5	33 58.5
100	24 21.2	200	35 41	33 58.86

Observed time of 300 vibrations, $2038^s.86$
Time of one, 6.7962

Arc: 205 + 395 at 0
264 335 at 200
283 317.5 at 350 vib's.

Set 7. Vibrations. Temperature, 40°.

Number.	Chronometer.	Number.	Chronometer.	300 vibrations.
0	$2^h\ 04^m\ 08^s$	300	$2^h\ 38^m\ 05^s$	$33^m\ 57^s.0$
10	05 15	310	39 12.5	33 57.5
20	06 22	320	40 20.5	33 58.5
30	07 30	330	41 28.5	33 58.5
40	08 38	340	42 37	33 59.0
50	09 46	350	43 45	33 59.0
100	15 26	200	26 46	33 58.25

Observed time of 300 vibrations, $2038^s.25$
Time of one, 6.7942

Arc: 180 and 420 at 0
254 343 at 200
279 321 at 350 vib's.

Set 8. Deflections. P. M. July 8, 1861.

Magnet Z 1 suspended, Z 6 deflecting; distance 1.0 foot.

E.	E.	10° 12′ 20″	13′ 20″	38°	$2u = 67°\ 40'\ 20''$
"	W.	302 32 10	32 50	37.5	
W.	E.	11 50 00	50 50	38	$2u = 68\ \ 14\ \ 05$
"	W.	303 36 00	36 40	38	
			Mean . . .	37.9	$u = 33\ \ 58\ \ 36$

Set 9. Deflections. Distance 1.3 foot.

W.	W.	321° 38′ 20″	39′ 00″	38°	$2u = 30°\ 32'\ 55''$
"	E.	352 11 10	12 00	38.5	
E.	W.	321 48 20	49 20	39.5	$2u = 29\ \ 59\ \ 40$
"	E.	351 48 00	49 00	38	
			Mean . . .	38.5	$u = 15\ \ 08\ \ 08$

Set 10. Deflections. July 9, 1861.

Z 1 suspended, Z 6 deflecting; distance 1.0 foot.

E.	E.	11° 07′ 20″	08′ 20″	42°	$2u = 68° 26' 40''$
"	W.	302 40 40	41 40	42.5	
W.	E.	10 45 00	45 50	43	$2u = 68\ 29\ 35$
"	W.	302 15 30	16 10	48	
			Mean . . .	43.9	$u = 34\ 14\ 04$

Observations for Torsion.

Torsion circle.	Scale.	Differences.	
90	300.5		
180	314.0	13.5	
360	286.5	27.5	Mean (4) = 13.9 = 14′.1
90	301.0	14.5	

Set 11. Deflections. Distance 1.3 foot. July 9, 1861.

W.	W.	321° 22′ 40″	23′ 30″	48.°5	$2u = 30° 20' 20''$
"	E.	351 43 00	43 50	46	
E.	W.	319 31 10	32 00	44	$2u = 31\ 19\ 10$
"	E.	350 50 10	51 20	47	
			Mean . . .	46.4	$u = 15\ 24\ 53$

Set 12. Vibrations. Temperature 39°. P. M. July 9, 1861.

Z 6 suspended.

0	$9^h\ 50^m\ 54^s$	300	$10^h\ 24^m\ 31^s$	$33^m\ 37^s.0$	
10	52 01.5	310	25 41	33 39.5	Observed time of
20	53 09	320	26 48.5	33 39.5	300 vibrations, $2019^s.08$
30	54 16.5	330	27 56	33 39.5	Time of one, 6.7303
40	55 23	340	29 02	33 39.0	
50	56 30	350	30 10	33 40.0	
100	10 02 06	200	13 17.5	33 39.08	

Arc: 204 and 462 at 0
255 363 " 200
280 319 " 350 vib's.

Set 13. Vibrations. Temperature, 41°. P. M. July 9, 1861.

0	$11^h\ 23^m\ 44^s$	300	$11^h\ 57^m\ 23^s$	$33^m\ 39^s.0$	
10	24 51	310	58 30	33 39.0	
20	25 58.5	320	59 38	33 39.5	Observed time of
30	27 06	330	12 00 45.5	33 39.5	300 vibrations, $2019^s.25$
40	28 12.5	340	01 52	33 39.5	Time of one, 6.7308
50	29 21	350	03 00	33 39.0	
100	34 59	200	11 46 10	33 39.25	

Arc: 170 and 435 at 0
262 340 " 200
288 312 " 352 vib's.

The combination of the deflection and vibration results is shown in the following table. The first three deflections having no corresponding vibrations, the value of m was deduced from the remaining five results viz: 0.316 at 41°.6 Fah., hence for the temperature t of these deflections we have $m = 0.316\ (1 - 0.0002\ (t - 41°.6))$. The vibrations have been referred to the temperature of the deflections by correcting the squares of the times by $1 - q\ (t' - t)$, the temperature of the deflections being t and that of the vibrations t'; they were also corrected for torsion $\left(1 + \frac{H}{F}\right)$. The average value of P has been used.

Set.	$lg \frac{m}{X}$	t	Set.	$lg\ mX$	$lg\ m$	X	m	
1	9.45303	39.°8	—	- - - - -	- - - - -	1.117	- - -	
2	9.46389	38.7	—	- - - - -	- - - - -	1.089	- - -	
3	9.46412	43.8	—	- - - - -	- - - - -	1.082	- - -	
4	9.46934	41.4	5	9.53037	9.49985	1.073	0.316	
8	9.46150	37.9	6	9.52832	9.49491	1.080	0.313	
9	9.46666	38.5	7	9.52844	9.49755	1.074	0.314	
10	9.46438	43.9	12	9.53615	9.40026	1.087	0.316	
11	9.47442	46.4	13	9.53604	9.50523	1.074	0.320	at 41°.6
					Mean . . .	1.084	0.316	

Netlik, Whale Sound. August 4, 1861.

Set 1. Vibrations. Magnet Z 6 suspended. Temperature, 48°.

Chronometer 4^h 40^m 04^s fast of Greenwich time.

0	2^h 25^m 53^s	300	2^h 59^m 32^s	33^m $39^s.0$	
10	27 01	310	3 00 40	33 39.0	Observed time of
20	28 08	320	01 47.5	33 39.5	300 vibrations, $2020^s.08$
30	29 15	330	02 55.5	33 40.5	Time of one, 6.7336
40	30 22	340	04 03	33 41.5	
50	31 29	350	05 10.5	33 41.0	
100	37 06.5	200	2 48 19.5	33 40.08	

Arc: 170.5 and 425 at 0
261 342 " 200
278 322 " 350 vib's.

Set 2. Vibrations. Temperature, 46°.

0	3^h 10^m $42^s.5$	300	3^h 44^m 24^s	33^m $41^s.5$	
10	11 50	310	45 32	33 42.0	Observed time of
20	12 57.5	320	46 39.5	33 42.0	300 vibrations, $2021^s.83$
30	14 04.5	330	47 46	33 41.5	Time of one, 6.7394
40	15 12	340	48 54	33 42.0	
50	16 20	350	50 02	33 42.0	
100	21 56.5	200	3 37 10.5	33 41.83	

Arc: 190 and 425 at 0
255 345 " 200
278 322 " 350 vib's.

Observations for Torsion.

Torsion circle.	Scale.	Differences.	
60° 30′	300		
150 30	320	20.0	
330 30	286	34.0	Mean (4) = 17.1 = 17′.3
60 30	300.5	14.5	

Set 3. Deflections.

Magnet Z 1 suspended, Z 6 deflecting. Distance 1 foot. P. M. August 4.

W.	E.	39° 24′ 10″	24′ 40″	42°	$2u = 16° 30′ 00″$
"	W.	332 54 00	54 50	40	
E.	"	332 45 20	45 40	39	$2u = 66\ 38\ 50$
"	E.	39 24 00	24 40	38	
			Mean . . .	39.7	$u = 33\ 17\ 12$

Combining the mean of set 1 and set 2 (6.7364) with the angle of set 3, correcting the first for torsion and referring it to 39°.7 Fah., we find

$$lg\frac{m}{X} = 9.45364 \quad \text{and} \quad X = 1.110$$

$$lg\, mX = 9.53614 \qquad m = 0.312 \text{ at } 39°.7 \text{ Fah.}$$

Upernavik, North Greenland. August 16, 1861.

At flagstaff. Chronometer 8^s fast of Greenwich time.

Set 1. Experiments of vibration. Temperature, 47°.

Magnet Z 1[1] suspended.

0	$5^h\ 15^m\ 47^s$	300	$5^h\ 50^m\ 38^s$	$34^m\ 51^s$	
10	16 57	310	51 47	34 50	Observed time of
20	18 06	320	52 57	34 51	300 vib'ns, $= 2091^s.17$
30	19 16	330	54 07	34 51	Time of one, 6.9706
40	20 25	340	55 17	34 52	
50	21 35	350	56 27	34 52	
100	27 24	200	39 01	34 51.17	

Arc: 193 and 413 at 0
266 334 " 200
282.5 318 " 350 vib's.

Set 2. Vibrations. Temperature, 47°.

0	$6^h\ 00^m\ 00^s$	300	$6^h\ 34^m\ 48^s$	$34^m\ 48^s$	
10	01 10	310	35 58	34 48	Observed time of
20	02 20	320	36 08	34 48	300 vibrations, $2088^s.08$
30	03 29	330	38 17.5	34 48.5	Time of one, 6.9603
40	04 39	340	39 27	34 48	
50	05 49	350	40 37	34 48	
100	11 37	200	23 12	34 48.08	

Arc: 194 and 399 at 0
261.5 338 " 200
280 320 " 350 vib's.

Set 3. Vibrations.[2] Temperature, 46°.

0	$7^h\ 01^m\ 18^s$	300	$7^h\ 35^m\ 09^s$	$34^m\ 51^s.0$	
10	02 27	310	36 18.5	34 51.5	Observed time of
20	03 36.5	320	37 28	34 51.5	300 vibrations, $2091^s.08$
30	04 46.5	330	38 37	34 50.5	Time of one, 6.9703
40	05 56	340	39 47	34 51.0	
50	07 06	350	40 57	34 51.0	
100	12 53	200	24 32	34 51.08	

Arc: 192 and 415 at 0
265 333 " 200
284.5 315.5 " 350 vib's.

Set 4. Deflections.

Magnet Z 1 suspended, Z 6 deflecting. Distance 1 foot.

E.	E.	45° 32′ 40″	33′ 40″	48°	$2u = 52° 40' 10''$
"	W.	352 52 40	53 20	44	
W.	E.	45 23 30	24 00	47	$2u = 52\ \ 45\ \ 35$
"	W.	352 37 50	38 30	46	
			Mean . . .	46.2	$u = 26\ \ 21\ \ 26$

[1] The correctness of the record is sustained by the resulting X.

[2] The record of 300 to 350 vibrations is 1^m too small, as appears plainly by comparing the times of 0, 100, 200, and 300 vibrations.

Set 5. Deflections. Distance 1.3 foot.

E.	E.	30° 36′ 30″	37′ 40″	47°	$2u = 23° 15' 55''$
"	W.	7 20 40	21 40	45	
W.	E.	30 39 40	40 10	43	$2u = 23\ 15\ 35$
"	W.	7 24 00	24 40	43	
			Mean . . .	44.5	$u = 11\ 37\ 53$

The mean result of set 1 and set 2 is 6.9654 at 47°, and of set 2 and set 3, 6.9653 at 46.5; if we correct these for torsion, and use $lg\ \pi^2 k$ (for Z 1) = 1.19212, and lgm (for Z 1) = 9.37310, the vibrations give X = 1.355 and 1.355. For the deflections we use lgm (for Z 6) 9.49164 and 9.49178 (the value of m being 0.310 at 50°) and find X = 1.349 and 1.372. The mean value of the four determinations is 1.358.

The magnetic moment of Z 6 appears to be very nearly constant, which is due to the age of the magnet; at 50° Fah. we have 0.308, 0.315, 0.311, 0.309, and 0.308 as found at Cambridge, Port Foulke, Netlik, Godhavn, and Washington, respectively.

Godhavn, Disco Island, Greenland. August and September, 1861.

Station in the garden at the rear of the Inspector's house.

Set 1. Vibrations. Z 6 suspended. September 7, 1861.

0	$2^h\ 28^m\ 42^s$	300	$2^h\ 55^m\ 25^s$	$26^m\ 43^s.0$	
10	29 34.5	310	56 19	26 44.5	Observed time of
20	30 28.5	320	57 12.5	26 44.0	300 vibrations, $1604^s.08$
30	31 22	330	58 06	26 44.0	Time of one, 5.3469
40	32 15.5	340	59 00	26 44.5	
50	33 09	350	59 53.5	26 44.5	
100	37 35.5	200	2 46 30	26 44.08	

Arc: 207 and 402 at 0 Temperature, 38°
261 339 " 200
288 312 " 350 vib's.

Set 2. Vibrations. Temperature, 38°.

0	$3^h\ 28^m\ 30^s$	300	$3^h\ 55^m\ 14^s$	$26^m\ 44^s.0$	
10	29 24	310	56 07	26 43.0	Observed time of
20	30 17	320	57 01	26 44.0	300 vibrations, $1603^s.58$
30	31 11	330	57 54	26 43.0	Time of one, 5.3453
40	32 04.5	340	58 48	26 43.5	
50	32 57	350	59 41	26 44.0	
100	37 25	200	3 46 19.5	26 43.58	

Arc: 185 and 425 at 0
257 347 " 200
280 320 " 350 vib's.

Set 3. Deflections. Z 1 suspended, Z 6 deflecting. Distance 1 foot.

E.	E.	244° 20′ 40″	21′ 40″	46°	
"	W.	205 30 40	31 40	47	$2u = 39° 04' 10''$
W.	E.	245 16 00	17 00	47	
"	W.	205 58 00	58 20	46	
E.	E.	244 19 20	20 20	46	
"	W.	205 28 20	29 10	46	$2u = 39\ 58\ 20$
W.	E.	245 17 50	18 40	45	
"	W.	204 12 40	12 40	45	
			Mean . . .	46	$u = 19\ 45\ 38$

During the above set a strong wind was blowing which disturbed the magnet a little.

	Set 4.	Deflections.	Distance 1.3 foot.	September 7, 1861.	
E.	E.	233° 43′ 40″	44′ 10″	45°	$2u = 17° 20' 40''$
"	W.	216 23 10	23 20	44	
W.	E.	234 10 00	11 00	40	$2u = 18\ 38\ 35$
"	W.	215 31 40	32 10	40	
			Mean. . . .	42.2	$u = 8\ 59\ 49$

Correcting for torsion and for difference of temperature we find

$$lg \frac{m}{X} = 9.24322 \text{ and } 9.24404 \qquad \text{hence } X = 1.763 \text{ and } 1.762$$
$$lg\ mX = 9.73564 \quad 9.73622 \qquad \text{and } m = 0.309 \text{ at } 46° \quad 0.309 \text{ at } 42°$$

Recapitulation of Preceding Values of Horizontal Force.

No.	Locality.	Latitude.	Longitude.	X	Date.	Observer.
1	Cambridge, Mass. . . .	42° 23′	71° 07	3.607	July, 1860	A. Sonntag
2	Pröven, North Greenland	72 23	55 33	1.576	Aug. 1860	A. Sonntag
3	Port Foulke, Smith Strait	78 18	73 00	1.084	July, 1861	H. G. Radcliff
4	Netlik, Whale Sound . .	77 08	71 22	1.110	Aug. 1861	H. G. Radcliff
5	Upernavik, N. Greenland	72 47	56 03	1.358	Aug. 1861	H. G. Radcliff
6	Godhavn, Disco, "	69 12	53 28	1.762	Sept. 1861	H. G. Radcliff
7	Washington, D. C., U. S.	38 53	77 00	4.296	June, 1862	C. A. Schott

The horizontal component X of the magnetic force is expressed in English units (feet and grains).

To the above two stations (Port Foulke and Netlik) at and near Smith Strait, I have added the following three stations occupied for horizontal force by Dr. Kane's party in 1854 and 1855.

Van Rensselaer Harbor,	$\phi = 78° 37'$	$\lambda = 70° 53'$	$X = 1.139$	(1854)
Hakluyt Island,	77 23	73 10	1.344	(1855)
Near Cape York,	76 03	68 00	1.573	(1855)

The observed horizontal force H, at these five stations, is represented by the formula

$$H = 1.250 - 0.11\ \Delta\phi - 0.21\ \Delta\lambda \cos\phi$$

$$\text{where } \Delta\phi = \phi - 77°.50 \text{ and } \Delta\lambda = \lambda - 71°.29$$

It was found, however, that the determination at Hakluyt Island, where the horizontal force appears too large, had the effect of inclining the isodynamic lines more than was warranted by values of more southern stations. I have, therefore, given the determination at Hakluyt the weight one-half, and find

$$H = 1.250 - 0.07\ \Delta\phi - 0.30\ \Delta\lambda \cos\phi$$

by means of which equation the isodynamic lines of 1.0, 1.1, 1.2, 1.3, and 1.4 were laid down on the chart.

The observations are represented as follows:—

	Obs. H.	Comp. H.	Diff.
Port Foulke	1.084	1.089	—0.005
Netlik	1.110	1.270	—0.160
Van Rensselaer Harbor	1.139	1.196	—0.057
Hakluyt	1.344	1.132	+0.212
Near Cape York	1.573	1.588	—0.015

The probable error of a single representation is ± 0.10, and of any resulting line ± 0.05 nearly.

MAGNETIC INCLINATION.

Observations and Results.

Port Foulke, SMITH STRAIT. July, 1861.

Observations at the Port Foulke Observatory.

Set 1. Needle II, marked end South. July 4, $10^h\ 13^m$ A. M.

Circle East.				Circle West.			
Face East		Face West.		Face East.		Face West.	
N.	S.	N.	S.	N.	S.	N.	S.
84° 55′	85° 07′	84° 45′	84° 45′	85° 15′	85° 07′	85° 15′	85° 15′
85 00	85 00	84 45	84 45	85 15	85 07	85 18	85 15

Mean . . . 84° 53′ 85° 13′

Mean. . . . 85° 03′

Needle II, marked end North.

Circle West.				Circle East.			
Face West.		Face East.		Face West.		Face East.	
85° 00′	85° 00′	85° 15′	85° 08′	84° 45′	85° 00′	84° 45′	84° 45′
84 52	84 53	85 15	85 08	84 45	85 00	84 52	84 52

Mean . . 85° 04′ 84° 50′

Mean . . . 84° 57′

Dip by needle II, 85° 00′.

Set 2. Needle III, marked end South. July 4, $11^h\ 43^m$ A. M.

E.				W.			
E.		W.		E.		W.	
85° 00′	85° 07′	85° 00′	85° 15′	84° 55′	84° 45′	84° 60′	84° 55′
15	20	15	30	60	60′	45	40

85° 13′ 84° 53′

85° 03′

Needle III, marked end North.

W.				E.			
W.		E.		W.		E.	
85° 00′	84° 55′	85° 00′	84° 55′	85° 30′	85° 45′	84° 45′	84° 65′
07	60	08	60	30	42	45	50

85° 01′ 85° 14′

85° 07′

Dip by needle III, 85° 05′

Set 3. Needle II, marked end South. July 5, $10^h\ 59^m$ A. M

E.				W.			
E.		W.		E.		W.	
85° 30′	85° 35′	84° 15′	84° 16′	85° 15′	85° 13′	85° 15′	85° 00′
15	30	17	17	17	15	15	05

84° 52′ 85° 12′

85° 02′

Needle II, marked end North.

W.				E.			
W.		E.		W.		E.	
85° 15′	85° 17′	85° 20′	85° 15′	84° 45′	84° 52′	84° 33′	84° 45′
10	05	25	15	45	52	45	50

85° 15′ 84° 46′

84° 00′

Dip by needle II, 85° 01′.

Set 4. Needle III, marked end South. July 5.

E.				W.			
E.		W.		E.		W.	
84° 50′	84° 50′	85° 00′	85° 15′	85° 15′	85° 20′	85° 13′	85° 02′
30	30	15	25	00	07	20	13

84° 57′ 85° 11′

85° 04

Needle III, marked end North.

W.				E.			
W.		E.		W.		E.	
85° 38′	85° 30′	85° 28′	85° 20′	84° 55′	85° 18′	84° 30′	84° 24′
40	30	28	20	67	13	60	62

85° 27′ 84° 56′

85° 11′

Dip by needle III, 85° 08′

Set 5. Needle II, marked end North. July 7 P. M.

W.				E.			
W.		E.		W.		E.	
84° 67′	84° 67′	85° 36′	85° 30′	84° 30′	84° 30′	84° 55′	85° 00′
55	50	32	30	26	30	77	20

85° 16′ 84° 48′

85° 02′

Needle II, marked end South.

E.				W.			
E.		W.		E.		W.	
84° 40′	84° 26′	84° 38′	84° 45′	85° 00′	85° 05′	85° 10′	85° 08′
32	38	60	60	00	03	15	05

84° 42′ 85° 06′

84° 54′

Dip by needle II, 84° 58′

Recapitulation of Results for Dip at Port Foulke, July 4–7, 1861.

No.	Needle.	Dip.	
Set 1	II	85° 00′	
" 2	III	85 05	
" 3	II	85 01	Resulting mean dip, 85° 02′
" 4	III	85 08	
" 5	II	84 58	

Littleton Island, Smith Strait. July 26 P. M.

Set 1. Needle II, marked end North.

E.				W.			
E.		W.		E.		W.	
85° 15′	85° 10′	84° 20′	84° 20′	84° 40′	84° 45′	84° 25′	84° 30′
20	20	25	25	63	55	30	30

84° 49′ 84° 40′

84° 44′

Needle II, marked end South.

W.				E.			
W.		E.		W.		E.	
84° 15′	84° 10′	84° 40′	84° 45′	84° 52′	84° 50′	84° 60′	85° 05′
15	15	40	45	60	52	55	00

84° 28′ 84° 56′

84° 42′

Dip by needle II, 84° 43′

Set 2. Needle III, marked end South.

E.				W.			
E.		W.		E.		W.	
84° 48′	84° 48′	84° 35′	84° 35′	84° 15′	84° 10′	84° 40′	84° 40′
48	48	42	42	22	22	30	30
84° 43′				84° 26′			
84° 35′							

Needle III, marked end North.

W.				E.			
W.		E.		W.		E.	
84° 22′	84° 15′	84° 30′	84° 30′	85° 05′	85° 05′	85° 00′	85° 05′
30	30	40	45	15	15	10	15
84° 30′				85° 08′			
84° 49′							

Dip by needle III, 84° 42′

RECAPITULATION OF RESULTS FOR DIP AT LITTLETON ISLAND, July 26, 1861.

	Needle.	Dip.	
Set 1	II	84° 43′	
" 2	III	84 42	Resulting mean dip, 84° 43′

Gale Point, CADOGAN INLET, SMITH STRAIT, July 28, 1861.

Set 1. Needle III, marked end South.

W.				E			
W.		E.		W.		E.	
85° 07′	85° 00′	85° 15′	85° 20′	85° 45′	85° 35′	85° 15′	85° 20′
00	03	18	20	45	35	07	10
85° 10′				85° 26′			
85° 18′							

Needle III, marked end North.

E.				W.			
E.		W.		E.		W.	
85° 35′	85° 30′	85° 05′	85° 10′	85° 35′	85° 40′	85° 15′	85° 15′
45	40	20	15	30	30	10	15
85° 25′				85° 24′			
85° 24′							

Dip by needle III, 85° 21′

Hakluyt Island, OFF WHALE SOUND. August 2 A. M., 1861.

Set 1. Needle II, marked end South.

E.				W.			
E.		W.		E.		W.	
85° 00′	85° 00′	85° 20′	85° 15′	84° 45′	85° 00′	84° 45′	84° 45′
00	00	25	20	45	00	55	50
85° 10′				84° 51′			
85° 00′							

Needle II, marked end North.

W.				E.			
W.		E.		W.		E.	
84° 45′	84° 50′	85° 00′	84° 65′	84° 55′	84° 50′	85° 20′	85° 15′
40	45	00	55	65	60	20	15
84° 53′				85° 07′			
85° 00′							

Dip by needle II, 85° 00′

Netlik, Whale Sound. August 4 P. M., 1861.

Set 1. Needle II, marked end South.

E.				W.			
E.		W.		E.		W.	
84° 50′	84° 55′	84° 55′	84° 55′	84° 60′	85° 00′	84° 45′	84° 45′
60	60	60	60	50	00	40	40
84° 57′				84° 50′			
84° 53′							

Needle II, marked end North.

W.				E.			
W.		E.		W.		E.	
84° 30′	84° 40′	85° 15′	85° 15′	84° 65′	84° 60′	85° 25′	85° 15′
30	30	30	30	50	50	25	20
84° 57′				85° 09′			
85° 03′							

Dip by needle II, 84° 58′

Godhavn, Disco Island, Greenland. August 31, 1861.

In garden at the rear of Inspector's house.

Set 1. Needle II, marked end South.

E.				W.			
E.		W.		E.		W.	
81° 60′	81° 55′	81° 30′	81° 30′	82° 12′	82° 12′	81° 45′	81° 45′
45	37	30	30	00	00	30	30
31° 40′				81° 52′			
81° 46′							

Needle II, marked end North.

W.				E.			
W.		E.		W.		E.	
81° 42′	81° 42′	81° 30′	81° 30′	82° 15′	81° 70′	82° 00′	82° 15′
45	45	37	45	00	45	00	00
81° 40′				82° 03′			
81° 51′							

Dip by needle II, 81° 49′

Set 2. Needle III, marked end South. September 13, 1861.

E.				W.			
E.		W.		E.		W.	
81° 45′	81° 40′	81° 45′	81° 40′	81° 35′	81° 32′	81° 45′	81° 50′
45	40	45	40	45	45	45	50
81° 42′				81° 43′			
81° 43′							

Needle III, marked end North.

W.				E.			
W.		E.		W.		E.	
82° 00′	82° 00′	81° 45′	81° 50′	82° 15′	82° 15′	81° 75′	82° 15′
05	15	50	60	18	15′	50	00
81° 58′				82° 10′			
82° 04′							

Dip by needle III, 81° 53′

Recapitulation of Results for Dip at Godhavn.

August 31, and September 13, 1861.

No.	Needle.	Dip.	
Set 1	II	81° 49′	
" 2	III	81 53	Resulting mean dip, 81° 51′

RECAPITULATION OF OBSERVED DIPS. Observations by H. G. Radcliff.					
No.	Locality.	Latitude.	Longitude.	Dip.	Date.
1	Port Foulke, Smith Strait	78° 18′	73° 00′	85° 02′	July, 1861
2	Littleton Island, Smith Strait . .	78 22	73 30	84 43	" "
3	Gale Point Cadogan Inlet	78 11	76 28	85 21	" "
4	Hakluyt Island, off Whale Sound .	77 23	73 10	85 00	August, 1861
5	Netlik, Whale Sound	77 08	71 22	84 58	" "
6	Godhavn, Disco Island, Greenland .	69 12	53 28	81 51	Aug. and Sept. 1861

To the above material available for the construction of an isoclinal chart of the vicinity of Smith Strait, I have added the following three determinations from Dr. Kane's expedition: Cape Grinnell,[1] latitude 78° 34′, longitude, 71° 34′, dip 85° 08′ in August, 1853. Marshall Bay,[2] latitude 78° 51′, longitude 68° 54′, dip 84° 49′ in September, 1853. Van Rensselaer Harbor, latitude 78° 37′, longitude 70° 53′, dip 84° 46′ in June, 1854.

The observed inclination I at these eight stations is represented by the equation—

$$I = 84^\circ.97 - 0.09\ \Delta\phi + 0.12\ \Delta\lambda\ \cos\phi$$

$$\text{where } \Delta\phi = \phi - 78^\circ.18 \text{ and } \Delta\lambda = \lambda - 72^\circ.36$$

The isoclinal lines on the chart were computed by the above formula; as in the case of the declinations and horizontal force determinations, the effect of the secular change between the interval of the two expeditions has been neglected.

The observations are represented as follows:—

	Observed I.	Computed I.	Difference.
Port Foulke	85.°03	84°.98	+0.°05
Littleton Island	84.72	84.98	—0.26
Gale Point	85.35	85.07	+0.28
Hakluyt Island	85.00	85.06	—0.06
Netlik	84.97	85.04	—0.07
Cape Grinnell	85.13	84.92	+0.21
Marshall Bay	84.82	84.83	—0.01
Van Rensselaer Harbor	84.77	84.90	—0.13

The probable error of any single representation is $\pm 0^\circ.13$, and of the resulting lines $\pm 0^\circ.05$ nearly.

The chart embodies the collective results for magnetic distribution at and near Smith Strait by the two American Polar Expeditions, and the years 1861, 1858, and 1858, may be taken for the respective epochs to which the graphical represen-

[1] Called "Bedevilled Reach" in the magnetic paper, and in the original record; it apparently comprised the coast between Capes Inglefield and Ingersoll. See chart in Vol. I of his narrative. See also Smithsonian Contributions to Knowledge: Magnetical Observations in the Arctic Seas, by E. K. Kane, M. D., U. S. N., etc. etc., reduced and discussed by C. A. Schott, p. 35 (published in November, 1858). The longitude has been slightly improved.

[2] For latitude and longitude see Astronomical Observations in the Arctic Seas, by E. K. Kane, M. D., U. S. N., etc. etc., reduced and discussed by C. A. Schott, p. 41, Smithsonian Contributions to Knowledge (May, 1860).

tations of the distribution of the declination, horizontal force, and inclination more strictly refer. The necessary use of systems of straight lines forbids their extension beyond the area marked out by the position of the observing stations.

Remarks on Observations of the Aurora Borealis.

It is a remarkable fact that during the winter 1860–1861 but three auroras were seen and recorded, and these were feeble and short displays. Possibly some more may have occurred, but they were too faint to be recognized.

The following notices are extracted from the records:—

"January 6, 1861. 11 A.M. Red aurora seen in the north, extending from horizon to zenith; lasted about 15 minutes. $7^h\ 5^m$ P.M. Aurora seen extending from N. to S. about 30°; lasted nearly half an hour. 9 P.M. Aurora seen the same as $7^h\ 45^m$, about 10 degrees nearer the horizon.

"January 11. Heavy mist hanging over the ice all day. 3 P.M. Aurora observed in the west; extended to the zenith; lasted about 10 minutes.

"February 16. An aurora visible at 9 P.M. in the west; lasted about 10 minutes; 25° to 30° high."

The direction in which the last two auroras were seen coincides in general with the direction of the north end of the magnetic needle, and with the position of an area of open water, present throughout the winter, and extending within a few miles to Port Foulke. This last remark may be of interest to those who are inclined to consider a large area of rising vapor as a favorable circumstance for the appearance of the aurora.[1] The noted paucity of auroral displays is unfavorable to the hypothesis of the coincidence of a maximum frequency with that of the solar spots, the greatest range of diurnal motion in the horizontal magnetic needle and the greatest number of magnetic disturbances, for all of which latter phenomena the years 1860–1861 include or approach the maximum value.

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[1] Meteorological Observations in the Arctic Seas, by Sir Francis Leopold M'Clintock, R. N., 1857–58–59. Smithsonian Contributions to Knowledge, May, 1862. Tabulation of auroras, with observations and notes by Dr. D. Walker.

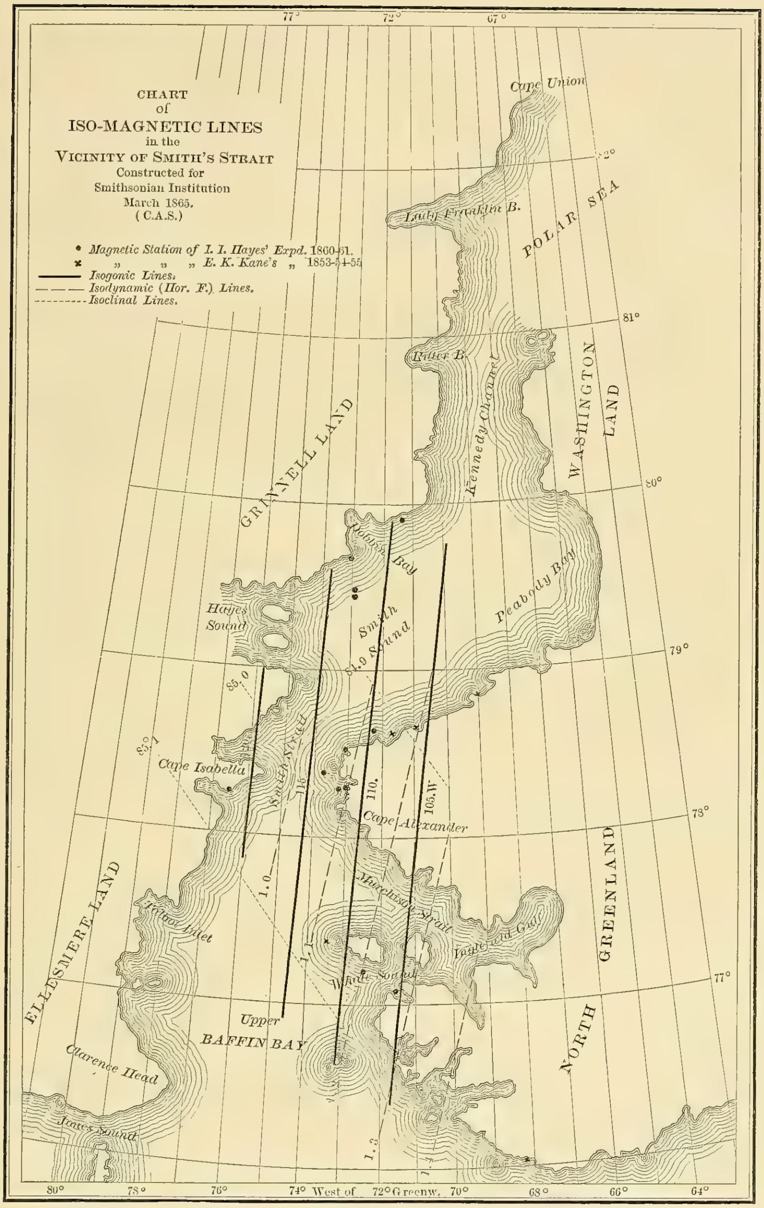


CHART
of
ISO-MAGNETIC LINES
in the
VICINITY OF SMITH'S STRAIT
Constructed for
Smithsonian Institution
March 1865.
(C.A.S.)
• Magnetic Station of I. I. Hayes' Expd. 1860-61.
× " " " E. K. Kane's " 1853-54-55
Isogonic Lines.
Isodynamic (Hor. F.) Lines.
Isoclinal Lines.
Cape Union
Lady Franklin B.
POLAR SEA
Kennedy Channel
WASHINGTON LAND
GRINNELL LAND
Peabody Bay
Hayes Sound
Smith Sound
Cape Isabella
Smith Strait
Cape Alexander
Murchison Strait
Inglefield Gulf
ELLESMERE LAND
NORTH GREENLAND
Whale Sound
Upper
BAFFIN BAY
Clarence Head
Jones Sound
110.
105.W
1.0
81°
80°
79°
78°
77°
80°
78°
76°
74° West of
72° Greenw.
70°
68°
66°
64°

PART III.

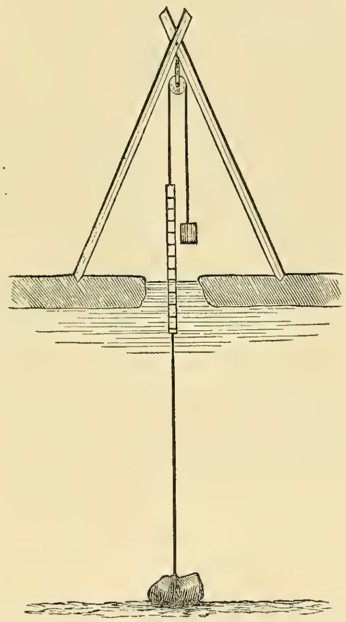
TIDAL OBSERVATIONS.

RECORD AND RESULTS

OF

TIDAL OBSERVATIONS.

The observations of the tides made by the Arctic Expedition of Dr. I. I. Hayes, at Port Foulke, Smith Strait, in 1860 and 1861, consist of two series; in the first are recorded the observed times and heights of high and low water in November and December, 1860, the greater part of it comprising half-hourly observations. The second series consists of observations of time and height of high and low water in June and July, 1861. These observations were taken every ten minutes about the time of high and low tide. The total extent of these two sets of observations is nearly two and a half months; a few accidental interruptions, however, occur in each series.



The tide gauge was of simple and effective construction, as shown in the annexed wood cut. It was a pulley gauge mounted upon the ice field in the harbor. The pulley and rope were supported by a tripod mounted over the hole cut through the ice; the tide rope was anchored at the bottom, and, in the first series, was divided off in feet by proper marks; in the second series a pole was inserted upon which the scale of feet was marked. The tide-rope was kept stretched by a counterpoise; this weight rose and fell with the tide. A gauge of such construction may be liable to disarrangement from the following sources: the rope may stretch, or the ice-field may have a slow motion and consequently incline the rope, or the stone may drag along the sloping bottom from the effects of currents or ice motion; if, from any cause, the apparatus fails, the zero level of the scale is easily lost, and generally cannot be recovered.

Sources of error in our observations have been specially examined, and such corrections as were found necessary have been applied. The results show the careful and conscientious manner in which these observations were made. For comparison with the results at Van Rensselaer Harbor[1] from Dr. Kane's observations in 1853 and 1854, the reductions are made on a uniform plan, as far as practicable, and in each case special reference is given.

Respecting the free access of the tide wave to the place of observation, the locality was suitably selected (see the small chart accompanying the discussion of the astronomical observations, Part I of this series). The apparatus was mounted in close vicinity to the brig, near the head of the port.

The observers, Messrs. H. G. Radcliff, G. F. Knorr, and C. C. Starr, are indicated, in the record, by their initials.

Record of Tide Observations at Port Foulke, Smith Strait.

First Series. 1860.

Nov. 17 P. M.		
H. W.		
1h 10m	18ft.	11in.
2 00	19	2
2 30	19	3
3 00	18	11
3 30	18	0
L. W.		
7 00	10	0
8 00	10	0
8 30	9	10
9 00	9	9
9 30	9	11
10 30	10	8
Nov. 18 A. M.		
H. W.		
2 00	15	6
2 40	16	0
3h 00m	16ft.	0in.
3 20	15	7
L. W.		
9 00	11	11
9 30	11	4
9 55	11	10
P. M.		
H. W.		
3 00	18	2
3 20	18	3
3 40	18	1
4 00	17	11
L. W.		
7 30	12	0
8 00	11	0
8 35	11	0
9 00	10	11
9h 35m	10ft.	6in.
10 00	10	1
10 20	10	7
Nov. 19 A. M.		
H. W.		
Not recorded		
L. W.		
Not recorded		
P. M.[2]		
H. W.		
3 15	14	0
4 00	14	6
4 30	14	9
5 00	14	6
5 30	13	11
6 00	13	1
7h 00m	11ft.	11in.
8 00	10	8
L. W.		
9 20	8	3
9 55	8	0
10 15	7	9
11 00	8	0
12 00	8	3
1 00	9	3
2 10	10	6
Nov. 20 A. M.		
H. W.		
3 00	11	3
4 00	12	0
5 00	12	0
5 15	11	11
L. W.		
Not recorded		
P. M.		
H. W.		
Not recorded		
L. W.		
9h 15m	9ft.	9in.
9 30	9	7
10 00	9	0
10 45	8	1
11 00	8	2
11 20	8	5
Nov. 21 A. M.		
H. W.		
Not recorded		

[1] Tidal observations in the Arctic Seas, by E. K. Kane, M. D., U. S. N.; made during the second Grinnell Expedition in 1853–54–55, at Van Rensselaer Harbor. Reduced and discussed by Charles A. Schott. Smithsonian Contributions to Knowledge, Vol. XIII, 1860.

[2] Between November 19 (P. M.) and December 10, inclusive, the new tide rope was used.

November, 1860.										
Mean time. A. M.	21st	22d	23d	24th	25th	26th	27th	28th	29th	30th
0^h 30^m	- - - -	7^{ft} 9^{in}	8^{ft} 6^{in}	9^{ft} 00^{in}	- - - -	9^{ft} 4^{in}	12^{ft} 3^{in}	13^{ft} 0^{in}	13^{ft} 9^{in}	18^{ft} 8^{in}
1	- - - -	7 11	8 2	8 1	- - - -	8 6	11 0	12 0	12 8	17 11
1 30	- - - -	8 1	8 2	8 0	- - - -	7 8	9 10	11 1	11 9	16 6
2	- - - -	8 4	8 3	7 8	- - - -	7 6	9 0	10 2	10 10	15 8
2 30	- - - -	8 8	8 4	7 8	- - - -	7 0	8 2	9 0	9 5	14 5
3	- - - -	9 9	8 11	7 10	- - - -	6 8	7 0	8 1	8 8	13 1
3 30	- - - -	10 5	9 4	8 0	- - - -	6 7	6 8	7 2	7 6	12 0
4	- - - -	11 1	9 9	8 2	- - - -	7 6	6 6	6 11	7 0	11 0
4 30	- - - -	11 0	10 4	9 0	- - - -	7 11	6 8	5 8	6 0	10 2
5	- - - -	(10 1)	11 2	9 8	- - - -	8 9	7 6	6 0	6 0	9 10
5 30	- - - -	11 6	12 1	10 11	- - - -	9 10	8 0	7 0	6 3	9 4
6	- - - -	12 10	13 0	12 0	- - - -	10 9	9 0	8 0	7 0	9 8
6 30	- - - -	13 00	13 7	12 9	- - - -	11 11	10 3	8 9	8 0	10 0
7	- - - -	13 4	14 0	13 4	- - - -	12 7	11 8	10 0	8 3	10 6
7 30	- - - -	13 5	14 2	14 6	- - - -	13 10	12 10	11 8	8 8	11 10
8	- - - -	13 2	14 3	15 0	- - - -	14 3	14 0	12 9	9 2	12 3
8 30	11^{ft} 0^{in}	12 11	- - - -	15 2	- - - -	15 0	15 10	14 0	12 2	14 5
9	10 10	12 7	14 0	15 4	- - - -	15 2	16 5	15 8	14 0	16 0
9 30	10 8	12 3	13 10	15 7	- - - -	15 4	17 3	16 7	16 0	17 4
10	- - - -	11 8	13 8	15 1	- - - -	15 7	17 8	17 11	17 0	18 9
10 30	10 0	11 4	12 11	14 1	- - - -	15 3	18 0	18 3	18 0	20 0
11	9 10	11 0	12 4	13 10	- - - -	- - - -	17 8	18 5	18 7	20 9
11 30	9 9	10 7	11 10	13 5	- - - -	- - - -	17 0	18 4	20 2	21 2
12	9 9	10 0	11 0	12 0	- - - -	- - - -	16 6	17 10	20 0	21 4
Observers:	- - - -	- - - -	K. ½ to 4	S. ½ to 4	- - - -	K. ½ to 4	K. ½ to 4	S. ½ to 4	R. ½ to 4	K. ½ to 4
"	- - - -	- - - -	S. 4½ to 8	K. 4½ to 8	- - - -	S. 4½ to 8	S. 4½ to 8	R. 4½ to 8	K. 4½ to 8	S. 4½ to 8
"	- - - -	- - - -	K.	S.	- - - -	R.	R.	K.	S.	R.

November, 1860.

Mean time. P. M.	21st	22d	23d	24th	25th	26th	27th	28th	29th	30th
0h 30m	10ft 1in	9ft 9in	10ft 3in	11ft 0in	- - - -	14ft 0in	15ft 8in	17ft 0in	19ft 8in	21ft 4in
1	10 4	9 11	10 0	10 8	- - - -	13 2	14 10	16 2	19 6	21 0
1 30	10 7	10 0	9 10	10 0	- - - -	12 1	13 8	15 0	18 6	20 4
2	11 1	10 1	9 9	9 1	- - - -	10 9	12 1	13 8	17 0	19 6
2 30	11 10	10 3	9 7	8 10	- - - -	9 9	10 10	12 1	16 3	18 11
3	12 0	11 0	9 8	8 10	- - - -	8 8	9 5	11 0	15 0	17 10
3 30	13 1	11 10	10 0	8 9	- - - -	8 0	9 0	9 1	13 8	16 1
4	13 2	12 0	10 4	9 0	- - - -	7 8	8 0	8 7	12 6	14 5
4 30	13 2	12 10	10 11	9 9	- - - -	7 7	7 8	8 0	11 6	13 0
5	13 3	13 0	11 7	10 0	- - - -	8 0	7 9	7 6	10 6	11 10
5 30	13 4	13 3	10 11	10 11	- - - -	8 10	7 10	7 0	10 0	11 0
6	13 1	13 10	10 2	11 2	- - - -	9 9	8 2	7 4	9 10	10 3
6 30	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	9 0	7 9	9 10	10 0
7	13 1	14 0	13 11	13 0	- - - -	11 0	9 8	8 4	9 9	10 4
7 30	12 10	14 0	14 0	13 7	- - - -	12 0	10 5	9 0	11 0	11 0
8	12 2	13 6	13 10	14 1	- - - -	12 10	11 6	10 4	11 10	11 8
8 30	11 10	13 0	13 8	14 0	- - - -	13 5	12 6	11 0	13 0	12 4
9	11 0	12 9	13 0	13 10	- - - -	14 1	13 9	12 5	13 8	13 2
9 30	10 4	12 3	12 8	13 9	- - - -	14 7	14 4	13 2	15 0	14 0
10	10 0	11 7	11 4	13 0	- - - -	14 10	14 8	14 0	16 0	15 4
10 30	9 7	11 0	11 7	12 1	- - - -	14 5	15 0	14 7	16 8	16 0
11	8 8	10 5	10 8	11 9	- - - -	14 0	15 0	14 9	17 5	16 8
11 30	8 0	9 8	10 0	11 0	- - - -	12 3	14 10	14 4	18 0	17 0
12	7 10	9 0	9 3	10 0	- - - -	10 10	14 0	14 1	18 0	17 6
Observers:	- - - -	K. $8\frac{1}{2}$ to 12	S. $\frac{1}{2}$ to 4	K. $\frac{1}{2}$ to 4	- - - -	K. $\frac{1}{2}$ to 4	K. $\frac{1}{2}$ to $3\frac{1}{2}$	S. $\frac{1}{2}$ to 4	R. $\frac{1}{2}$ to 4	K. $\frac{1}{2}$ to 4
"	- - - -	- - - -	K. $4\frac{1}{2}$ to 6	S. $4\frac{1}{2}$ to 6	- - - -	S. $4\frac{1}{2}$ to 8	S. 4 to $5\frac{1}{2}$	R. $4\frac{1}{2}$ to $6\frac{1}{2}$	K. $4\frac{1}{2}$ to 6	S. 4 to 8
"	- - - -	- - - -	S. 7 to 8	K. 7 to 8	- - - -	R.	R. 6 to $7\frac{1}{2}$	K. $6\frac{1}{2}$ to 8	S. $6\frac{1}{2}$ to 9	K.
"	- - - -	- - - -	K.	S.	- - - -	- - - -	K.	S.	R.	- - - -

December, 1860.

Mean time. A. M.	1st	2d	3d	4th[1]	5th	6th	7th	8th	9th
0h 30m	17ft 9in	16ft 9in	16ft 0in	16ft 0in	13ft 8in	12ft 0in	12ft 0in	10ft 0in	11ft 11in
1	17 10	17 4	16 3	16 0	14 3	13 2	12 2	10 9	10 11
1 30	17 1	17 0	16 6	16 0	15 0	14 0	12 4	11 0	10 7
2	16 4	16 6	17 0	16 0	16 0	14 11	13 6	11 6	9 7
2 30	15 1	15 10	16 10	16 2	16 6	15 8	13 9	12 3	9 4
3	14 3	14 8	16 7	16 2	17 0	16 4	14 3	13 0	9 0
3 30	13 0	14 0	15 0	16 2	17 6	17 2	14 10	13 10	9 5
4	12 3	13 6	14 0	16 0	17 5	18 9	16 0	14 2	10 1
4 30	11 8	12 0	13 8	15 9	18 0	18 11	16 10	16 0	14 0
5	10 2	11 0	12 10	14 6	17 3	19 1	17 6	16 10	14 4
5 30	10 0	10 1	12 0	13 9	16 10	18 10	17 10	17 8	16 5
6	9 8	9 9	11 3	13 0	16 4	18 3	18 0	18 5	17 10
6 30	9 6	9 5	10 2	12 6	15 7	17 9	18 0	19 0	18 3
7	9 9	9 5	10 0	11 9	14 9	16 10	18 2	19 5	19 0
7 30	10 4	9 8	9 10	11 0	14 3	16 0	18 0	19 8	19 5
8	11 0	10 0	10 2	10 5	13 10	15 10	17 8	19 2	19 10
8 30	12 8	11 1	10 6	10 6	13 6	15 0	17 6	19 7	20 0
9	14 0	12 0	10 10	11 0	13 5	14 2	16 9	19 8	20 0
9 30	15 8	13 2	11 10	14 0	13 0	14 4	16 3	19 0	19 4
10	17 0	14 1	13 3	- - - -	12 11	13 10	15 9	18 1	19 0
10 30	18 0	15 10	14 7	- - - -	13 2	13 5	15 0	17 2	18 6
11	19 0	17 0	15 10	13 4	13 10	13 6	14 5	16 0	18 0
11 30	20 0	18 1	16 6	15 2	14 2	13 6	13 11	15 8	16 6
12	20 6	19 0	17 5	17 4	15 0	13 10	13 9	14 3	15 6
Observers:	S. ½ to 4	R. ½ to 4	K. ½ to 4	S. ½ to 4	R. ½ to 4	S. 4½ to 8	S. ½ to 4	R. ½ to 4	K. ½ to 4½
"	R. 4½ to 8	K. 4½ to 8	S. 4½ to 8	R. 4½ to 8	K. 4½ to 8	R. 8½ to 12	R. 4½ to 8	K. 4½ to 8	S. 5 to 8
"	K.	S.	R.	K.	S.			S.	R.

[1] Between 2½ and 9½ the tide rope was foul of the specimen rope; at 10½ it was taken up, repaired, and put down again.

December, 1860.									
Mean time. P. M.	1st	2d	3d	4th	5th	6th	7th	8th	9th
0^h 30^m	20^{ft} 8^{in}	20^{ft} 0^{in}	18^{ft} 5^{in}	18^{ft} 0^{in}	16^{ft} 0^{in}	14^{ft} 1^{in}	13^{ft} 8^{in}	13^{ft} 5^{in}	15^{ft} 0^{in}
1	20 9	20 2	19 0	19 0	16 5	14 6	13 10	13 0	14 0
1 30	20 4	20 4	19 6	19 7	17 0	15 7	14 0	12 10	13 1
2	19 8	20 2	19 0	20 0	18 0	16 4	15 2	12 10	11 7
2 30	19 0	20 0	18 6	20 2	18 6	17 1	15 4	13 0	10 0
3	18 4	19 2	17 8	20 3	19 0	17 9	16 0	13 6	10 11
3 30	17 0	18 0	17 0	20 2	19 0	18 4	16 7	14 0	12 0
4	16 0	17 3	17 0	20 0	19 6	18 6	17 0	14 7	13 0
4 30	14 0	16 0	16 11	19 8	- - - -	19 1	17 6	15 8	13 9
5	12 10	14 11	16 0	19 0	19 6	19 1	17 10	16 4	14 0
5 30	12 0	13 6	15 1	18 0	19 4	19 2	18 0	17 0	15 1
6	10 8	12 0	13 10	17 3	18 4	19 0	18 2	17 10	16 0
6 30	10 0	11 1	12 6	16 0	17 9	18 0	19 0	18 0	17 2
7	9 10	10 1	11 0	14 11	16 10	17 6	18 10	19 0	17 6
7 30	9 8	9 9	10 3	14 0	15 0	16 10	18 0	19 0	17 8
8	9 6	9 3	9 4	13 2	14 0	16 0	17 10	18 10	17 10
8 30	10 0	9 6	9 9	12 1	13 0	15 1	17 1	18 0	18 0
9	10 5	10 0	9 11	11 10	12 3	14 2	16 2	17 4	18 0
9 30	11 10	10 5	10 4	11 6	11 6	13 4	15 8	16 8	17 9
10	12 4	11 0	11 0	11 0	11 0	12 0	14 0	15 10	- - - -
10 30	13 10	12 0	12 4	11 0	10 10	10 11	13 8	15 0	- - - -
11	14 6	12 10	13 6	12 0	10 10	9 8	12 11	14 0	- - - -
11 30	15 10	14 0	14 6	12 6	11 0	9 9	12 0	13 0	- - - -
12	16 0	14 11	15 2	13 0	11 9	10 10	11 8	12 0	- - - -
Observers:	S. ½ to 4	R. ½ to 4	K. ½ to 4	S. ½ to 4	R. ½ to 4	K. ½ to 4	S. ½ to 4	R. ½ to 4	K. ½ to 4
"	R. 4½ to 6	K. 4½ to 6	S. 4½ to 6	R. 4½ to 6	K. 4½ to 6	S. 4½ to 6	R. 4½ to 6	K. 4½ to 6	S. 4½ to 6
"	K. 6½ to 8	S. 6½ to 8	R. 6½ to 8	S. 8½ to 12	S. 6½ to 8½	R. 6½ to 8	K. 6½ to 8	S. 6½ to 8	R. 6½ to 8
"	S.	R.	K.		R.	K.	S.	R.	K.

December, 1860.

10th A. M.

L. W.

2^h	00^m	10^{ft}	0^{in}
2	30	9	11
3		10	2

S.

H. W.

8		19	6
8	30	20	0
9		21	0
9	30	21	0
10		20	6
10	30	20	0

R.

P. M.

L. W.

2	30	12	6
3		12	0
3	30	12	0
4		12	4

K.

Tide rope taken up and remarked, and put down again.

H. W.

Not observed

11th A. M.

L. W.

Not observed

H. W.

Not observed

P. M.

L. W.

3	30	13	1
4		12	9
4	30	12	1
5		12	6
5	30	12	11
6		13	1

S.

H. W.

9	30	19	0
10		19	6
10	30	19	9
11		19	6
11	30	19	0

R.

12th A. M.

L. W.

4^h	00^m	11^{ft}	6^{in}
4	30	11	5
5		11	10

K.

H. W.

10		22	0
10	30	22	9
11		23	0
11	30	22	10
12		22	2

S.

P. M.

L. W.

4		12	6
4	30	12	2
5		11	11
5	30	11	11
6		12	0
6	30	12	4

R.

H. W.

10	30	19	5
11		19	8
11	30	19	8
12		19	2

K.

13th A. M.

L. W.

4	30	11	4
5		11	0
5	30	11	4

R.

H. W.

11		23	0
11	30	23	0
12		22	11
12	30	22	8

S.

P. M.

L. W.

5		12	0
5	30	11	10
6		12	2

K.

H. W.

11	30	19	6
12		19	9
12	30	19	3

R.

14th A. M.

L. W.

5^h	30^m	11^{ft}	10^{in}
6		11	9
6	30	12	1

S.

P. M.

H. W.

0		23	10
0	30	23	10
1		23	0

K.

L. W.

6		12	0
6	30	11	9
7		11	9
7	30	12	0

R.

15th A. M.

H. W.

0		19	8
0	30	19	9
1		19	9
1	30	19	1

S.

L. W.

6	30	12	0
7		11	10
7	30	12	5

K.

P. M.

H. W.

0	30	22	9
1		23	
1	30	22	9

R.

L. W.

7		12	0
7	30	12	0
8		12	2

S.

16th A. M.

H. W.

1		19	0
1	30	19	2
2		19	2
2	30	18	9

K.

L. W.

7^h	00^m	12^{ft}	4^{in}
7	30	12	4
8		12	10

R.

P. M.

H. W.

1	30	22	6
2		22	10
2	30	22	1

S.

L. W.

7	30	13	3
8		12	10
8	30	13	0

K.

17th A. M.

H. W.

1	30	19	8
2		19	8
2	30	19	4

R.

L. W.

Incorrectly observed

P. M.

H. W.

2		22	0
2	30	22	1
3		21	8

K.

L. W.

8	30	12	11
9		12	9
9	30	13	0

R.

18th A. M.

H. W.

2	30	18	6
3		18	7
3	30	18	1

S.

L. W.

8	30	14	0
9		13	4
9	30	13	9

K.

P. M.

H. W.

3^h	00^m	20^{ft}	9^{in}
3	30	20	5
4		20	0

R.

L. W.

9		13	0
9	30	12	11
10		13	1

S.

19th A. M.

H. W.

3		18	0
3	30	18	5
4		18	5
4	30	18	0

K.

L. W.

9	30	14	0
10		14	3
10	30	14	8

R.

P. M.

H. W.

3	30	20	2
4		20	0
4	30	19	10

S.

L. W.

9	30	13	7
10		13	4
10	30	13	4
11		13	10

K.

20th A. M.

H. W.

4		17	10
4	30	18	0
5		18	0
5	30	17	10

R.

L. W.

10		15	0
10	30	15	0
11		15	0
11	30	15	2
12		15	10

S.

<table>
<tr><th colspan="5">December, 1860.</th></tr>
<tr>
<td>P. M.
H. W.
4^h 30^m 18^{ft} 7^{in}
5 18 10
5 30 18 10
6 18 3
K.

L. W.
10 30 13 0
11 12 10
11 30 12 11
12 13 3
R.

21st A. M.
H. W.
Not observed

L. W.
9 30 15 11
10 15 8
10 30 15 1</td>
<td>11^h 00^m 15^{ft} 1^{in}
11 30 15 1
12 15 6
S.

P. M.
H. W.
4 17 10
4 30 18 0
5 18 0
5 30 18 0
6 17 9
R.
L. W.
10 14 1
10 30 13 9
11 13 7
11 30 13 3
12 13 3
S.

22d A. M.
H. W.
4 30 17 2
5 17 6</td>
<td>5^h 30^m 17^{ft} 10^{in}
6 18 1
6 30 18 3
7 18 3
7 30 17 9
K.

L. W.
10 30 16 3
11 15 11
11 30 15 7
12 15 2
12 30 15 2
1 15 2
1 30 15 2
2 15 2
2 30 15 7
R.

P. M.
H. W.
4 30 16 4
5 16 9
5 30 17 0
6 17 0</td>
<td>6^h 30^m 17^{ft} 2^{in}
7 17 4
7 30 17 0
S.

L. W.
11 30 14 0
12 13 3
12 30 13 3
1 13 3
1 30 13 3
2 13 10
K.

23d A. M.
H. W.
5 16 6
5 30 16 10
6 17 6
6 30 18 0
7 18 3
7 30 18 10
8 19 0</td>
<td>8^h 30^m 18^{ft} 10^{in}
9 18 9
R.

L. W.
11 17 3
11 30 16 9
12 16 0
12 30 15 11
1 15 8
1 30 15 0
2 15 4
S.

P. M.
H. W.
6 30 17 8
7 18 2
7 30 18 3
8 18 2
8 30 17 9
K.</td>
</tr>
</table>

The rope used November 17 and 18 was measured, and its 36 feet mark was found to be 30 feet 8 inches; a proportionate reduction of the readings, as recorded, is therefore to be made.

A new rope was used between November 19 and December 10; the distances from foot mark to foot mark, along its range, are recorded as follows:—

0 to 1 foot	- - - inches		11 to 12 feet	11 inches
1	2	10.5	12	13	10
2	3	11.25	13	14	11.5
3	4	11.12	14	15	10.25
4	5	10.5	15	16	10.5
5	6	11.25	16	17	11
6	7	11.5	17	18	13
7	8	10.25	18	19	9.5
8	9	11.75	19	20	17.5
9	10	10.	20	21	13.75
10	11	11.25	21	22	13

From the above the following table of corrected measures has been made out:—

Mark on rope.	Corresponding true reading.	Mark on rope.	Corresponding true reading.
0 feet	0.0 feet	11 feet	10.1 feet
1	1.0	12	11.0
2	1.9	13	11.9
3	2.8	14	12.8
4	3.7	15	13.7
5	4.6	16	14.6
6	5.5	17	15.4
7	6.5	18	16.5
8	7.4	19	17.3
9	8.3	20	18.8
10	9.2	21	20.0
		22	21.0

This table might be used for correcting all observed heights of the tide between November 19 and December 10; but I thought it preferable to suppose that the rope was at first correctly marked but changed afterwards. An examination of the mean level of the sea indicated a small but somewhat abrupt increase in the reading after the first high water of November 29th, and again a similar increase after the first high water of December 4th; I have therefore applied *no* correction to the readings of the rope between November 19th and November 29th, 2 P. M.; and have applied *half* the correction between the last named date and December 4th, 6 A. M. It seems that the apparatus was not in good working order during the last high tide as the readings for four hours indicate some defect. After December 4, 6 A. M., the full correction was applied. On the 11th of December the rope was taken up and re-marked, and the readings from and after this date must be taken as correct.

To obtain a closer determination than half an hour of the time of high and low tide, the heights were plotted and a curve drawn through the points with a free hand from which the time was made out with an uncertainty generally not exceeding ten minutes.

The times and corresponding heights will be given after the record of series two of observations; see Table I.

Record of Tide observations at Port Foulke, Smith Strait.
Second series. 1861.

June 6 A. M.	9^h 30^m $20^{ft}.3$	11^h 10^m $17^{ft}.85$	June 8 A. M.	3^h 50^m $12^{ft}.1$
H. W.	40 .45	20 .8	L. W.	4 00 .0
10^h 00^m $17^{ft}.8$	50 .6	30 .65	4^h 10^m $13^{ft}.0$	10 11.8
10 .85	10 00 .7	40 .4	20 12.85	20 .9
20 .8	10 .75	K.	30 .75	30 .6
30 .75	20 .8	P. M.	40 .5	40 .5
40 .7	30 .8	L. W.	50 .4	50 .5
50 .55	40 .8	4 00 11.55	5 00 .25	5 00 .52
R.	50 .75	10 .5	10 .1	10 .55
P. M.	11 00 .65	20 .5	20 .05	20 .6
L. W.	10 .6	30 .5	30 .05	30 .7
3 00 12.25	R.	40 .5	40 .05	S.
10 .05	June 7 A. M.	50 .5	50 .05	10 00 20.7
20 .0	L. W.	5 00 .9	6 00 .25	10 - - -
30 11.95	3 30 13.1	K.	K.	20 21.45
40 .95	40 12.8	H. W.	H. W.	30 .6
50 .9	50 .6	9 30 20.5	10 00 18.1	40 .75
4 00 .95	4 00 .45	40 .6	10 .2	50 .9
10 .95	10 .35	50 .9	20 .35	11 00 22.0
20 .95	20 .25	10 00 21.0	30 .5	10 .1
30 12.05	30 .15	10 .1	40 .65	20 .15
40 .15	40 .1	20 .4	50 .7	30 .2
50 .2	50 .15	30 .5	11 00 .7	40 .2
5 00 .25	5 00 .15	40 .6	10 .72	50 .1
10 .3	10 .2	50 .65	20 .7	12 00 .0
20 .5	20 .25	11 00 .65	30 .62	S.
R.	30 .3	10 .65	40 .45	June 9 A. M.
P. M.	R.	20 .65	S.	L. W.
H. W.	H. W.	30 .6	P. M.	4 30 13.3
9 00 19.65	10 50 18.0	40 .35	L. W.	40 .1
10 .9	11 00 17.9	K.	3 30 12.55	50 12.9
20 20.1			40 .38	

Second series, 1861.—*Continued.*

June 9 A. M.

L. W.

5^h	00^m	$12^{ft}.8$
	10	.15
	20	.4
	30	.15
	40	.1
	50	.0
6	00	.0
	10	.0
	20	.1
	30	.2

S.

H. W.

10	30	18.0
	40	.1
	50	.4
11	00	.55
	10	.65
	20	.7
	30	.8
	40	.8
	50	.75
12	00	.75
	10	.65

R.

P. M.

L. W.

4	10	12.55
	20	.35
	30	.15
	40	.0
	50	----
5	00	11.75
	10	.7
	20	.65
	30	.65
	40	.65
	50	.7
6	00	.75

R.

P. M.

H. W.

11	00	21.6
	10	.8
	20	22.05
	30	.2
	40	.3
	50	.35
12	00	.4
	10	.4
	20	.4
	30	.35
	40	.25

R.

June 10 A. M.

L. W.

5^h	20^m	$12^{ft}.9$
	30	.7
	40	.45
	50	.4
6	00	.3
	10	.05
	20	.0
	30	.0
	40	.0
	50	.0
7	00	.05
	10	.15
	20	.3

R.

H. W.

11	00	18.2
	10	.5
	20	.6
	30	.8
	40	.9
	50	19.0
12	00	.05
	10	.1
	20	.1
	30	.1
	40	.1
	50	18.9

K.

P. M.

L. W.

5	00	12.5
	10	.4
	20	.25
	30	.1
	40	.0
	50	11.9
6	00	.9
	10	.9
	20	.9
	30	.9
	40	12.0
	50	.1

K.

H. W.

11	30	21.9
	40	22.3
	50	.3
0	00	.4
	10	.6
	20	.7
	30	.8
	40	.8
0^h	50^m	$22^{ft}.8$
1	00	.7
	10	.65
	20	.55

K.

June 11 A. M.

L. W.

5	40	13.2
	50	12.9
6	00	.7
	10	.45
	20	.3
	30	.15
	40	.0
	50	11.9
7	00	.9
	10	.9
	20	.9
	30	.9
	40	.95
	50	12.05
8	00	.2

K.

P. M.

H. W.

0	00	18.5
	10	.7
	20	.75
	30	.8
	40	.9
	50	.9
1	00	.9
	10	.85
	20	.8
	30	.75

S.

L. W.

5	30	12.4
	40	.3
	50	.3
6	00	.2
	10	11.95
	20	.9
	30	.9
	40	.9
	50	.9
7	00	.9
	10	12.0
	20	.1
	30	.2

S.

June 12 A. M.

H. W.

0^h	10^m	$21^{ft}.4$
	20	.6
	30	.8
	40	.9
	50	22.1
1	00	.15
	10	.2
	20	.2
	30	.2
	40	.1
	50	.0
2	00	21.9

S.

L. W.

6	30	12.7
	40	.4
	50	.2
7	00	.0
	10	11.9
	20	.75
	30	.7
	40	.6
	50	.6
8	00	.6
	10	.6
	20	.7
	30	.8

S.

P. M.

H. W.

0	30	18.0
	40	.2
	50	.3
1	00	.4
	10	.5
	20	.55
	30	.6
	40	.6
	50	.6
2	00	.55
	10	.5
	20	.35

K.

L. W.

7	00	12.4
	10	.3
	20	.25
	30	.2
	40	.2
	50	.2
8	00	.2
8^h	10^m	$12^{ft}.2$
	20	.4

K.

June 13 A. M.

H. W.

0	40	20.7
	50	.9
1	00	21.2
	10	.35
	20	.5
	30	.6
	40	.7
	50	.7
2	00	.7
	10	.7
	20	.65
	30	.4

K.

L. W.

7	00	12.9
	10	.7
	20	.5
	30	.3
	40	.1
	50	.0
8	00	11.9
	10	.9
	20	12.1
	30	.2

K.

P. M.

H. W.

1	00	17.9
	10	18.1
	20	.2
	30	.35
	40	.45
	50	.6
2	00	.75
	10	.75
	20	.75
	30	.75
	40	.75
	50	.75
3	00	.55
	10	.45

K.

L. W.

7	20	13.4
	30	.25
	40	.2
	50	.15

Second series, 1861.—*Continued.*

June 13 P. M.

L. W.

8^h	00^m	$13^{ft}.15$
	10	.15
	20	.15
	30	.2
	40	.45

K.

June 14 A. M.

H. W.

1	30	20.7
	40	.9
	50	21.0
2	00	.2
	10	.3
	20	.35
	30	.35
	40	.35
	50	.35
3	00	.35
	10	.3
	20	.25
	30	20.9

K.

L. W.

7	40	13.0
	50	12.9
8	00	.7
	10	.4
	20	.2
	30	.1
	40	.0
	50	11.9
9	00	.9
	10	12.1

K.

P. M.

H. W.

1	50	17.9
2	00	18.0
	10	.15
	20	.3
	30	.4
	40	.5
	50	.6
3	00	.65
	10	.65
	20	.65
	30	.65
	40	.65
	50	.45

K.

L. W.

8	00	13.9
	10	.5

8^h	20^m	$13^{ft}.35$
	30	.25
	40	.2
	50	.15
9	00	.1
	10	.05
	20	.05
	30	.1
	40	.3
	50	.4

K.

June 15 A. M.

H. W.

2	10	19.85
	20	20.1
	30	.2
	40	.3
	50	.45
3	00	.5
	10	.55
	20	.55
	30	.55
	40	.55
	50	.55
4	00	.4

K.

L. W.

8	30	12.8
	40	.6
	50	.4
9	00	.2
	10	.0
	20	11.9
	30	.9
	40	.9
	50	.8
10	00	.8
	10	.8
	20	.8
	30	.9
	40	12.0

K.

P. M.

H. W.

2	30	17.8
	40	.9
	50	18.1
3	00	.3
	10	.5
	20	.6
	30	.6
	40	.9
	50	.9
4	00	19.0
	10	.0
	20	.0

4^h	30^m	$19^{ft}.0$
	40	18.95
	50	.95
5	00	.8

K.

L. W.

9	00	14.4
	10	.3
	20	.1
	30	.1
	40	.05
	50	.0
10	00	.0
	10	.0
	20	.0
	30	.1

K.

June 16 A. M.

H. W.

2	40	20.2
	50	.4
3	00	.5
	10	.65
	20	.65
	30	.65
	40	.7
	50	.7
4	00	.7
	10	.7
	20	.65
	30	.55
	40	.3

K.

9 30
Pole carried away by a strong S. W. gale

June 17 A. M.

The anchor of the pole was taken up, and the pole repaired and replaced. The bottom is sloping, and the zero point therefore differs from that of the former observations.

P. M.

H. W.

3	40	17.9
	50	18.1

4^h	00^m	$18^{ft}.4$
	10	.9
	20	.95
	30	19.2
	40	.4
	50	.7
5	00	.9
	10	20.0
	20	.1
	30	.3
	40	.5
	50	.6
6	00	.6
	10	.75
	20	.75
	30	.75
	40	.6
	50	.4

K.

Strong wind from S. W.

L. W.

10	10	16.0
	20	15.9
	30	.6
	40	.4
	50	.1
11	00	14.9
	10	.8
	20	.5
	30	.4
	40	.3
	50	.3
12	00	.1
	10	.1
	20	.1
	30	.25

K.

Strong wind from S. W.

June 18 A. M.

H. W.

6	00	18.7
	10	.8
	20	.9
	30	19.0
	40	.0
	50	.0
7	00	.0
	10	18.8
	20	.5

K.

Strong wind from S. W.

L. W.

10^h	30^m	$13^{ft}.75$
	40	.45
	50	.25
11	00	.0
	10	12.9
	20	.8
	30	.75
	40	.7
	50	.6
12	00	.5
	10	.35
	20	.3
	30	.3
	40	.3
	50	.35
1	00	.4
	10	.42
	20	.45

S.

Strong wind from S. W.

P. M.

H. W.

4	30	16.9
	40	17.25
	50	.7
5	00	.95
	10	18.15
	20	.35
	30	.65
	40	19.0
	50	.35
6	00	.5
	10	.7
	20	.8
	30	20.0
	40	.2
	50	.4
7	00	.5
	10	.6
	20	.6
	30	.65
	40	.65
	50	.65
8	00	.6
	10	.5
	20	.4
	30	.3

S.

Strong wind from S. W.

L. W.

11	00	16.6
	10	.4
	20	.1
	30	15.9
	40	.6

Second series, 1861.—*Continued.*

June 18 P. M.

L. W.

11h	50m	15ft.35
12	00	.1
	10	14.9
	20	.6
	30	.4
	40	.3
	50	.1
1	00	.05
	10	.0
	20	13.9
	30	.9
	40	.9
	50	.9
2	00	14 .0
	10	.1

S.

Strong wind from S. W.

June 19 A. M.

H. W.

6	30	18.6
	40	.75
	50	.8
7	00	.95
	10	19.0
	20	.05
	30	.1
	40	.1
	50	.0
8	00	.0
	10	18.9
	20	.75

S.

Strong wind from S. W.

P. M.

L. W.

0	00	13.25
	10	.0
	20	12.9
	30	.7
	40	.5
	50	.5
1	00	.45
	10	.4
	20	.3
	30	.4
	40	.45
	50	.5

R.

Strong wind from S. W.

H. W.

6h	30m	19ft.7
	40	.9
	50	20.15
7	00	.4
	10	.65
	20	.9
	30	21.05
	40	.2
	50	.35
8	00	.45
	10	.55
	20	.6
	30	.65
	40	.65
	50	.6
9	00	.6
	10	.5

R.

Strong wind from S. W.

L. W.

Not observed

June 20 A. M.

H. W.

7	40	18.65
	50	.75
8	00	.95
	10	.95
	20	19.05
	30	.05
	40	.05
	50	.05
9	00	.0
	10	18.95
	20	.8

\- - - -

P. M.

L. W.

1	00	13.1
	10	12.9
	20	.9
	30	.5
	40	.5
	50	.45
2	00	.45
	10	.45
	20	.45
	30	.45
	40	.45
	50	.6

\- - - -

Pole taken up

P. M.

H. W.

8h	00m	20ft.5
	10	.7
	20	.9
	30	21.0
	40	.3
	50	.5
9	00	.6
	10	.7
	20	.7
	30	.7
	40	7
	50	.65
10	00	.5

\- - - -

June 21 A. M.

L. W.

1	30	14.7
	40	.3
	50	.1
2	00	13.9
	10	.5
	20	.2
	30	12.9
	40	.6
	50	.5
3	00	.5
	10	.5
	20	.7

\- - - -

H. W.

8	10	17.65
	20	.8
	30	.95
	40	18.2
	50	.25
9	00	.35
	10	.4
	20	.4
	30	.4
	40	.4
	50	.4
10	00	.3
	10	.2

\- - - -

P. M.

L. W.

1	40	12.8
	50	.5
2	00	.3
	10	.0
	20	11.75
	30	.5
	40	.2
	50	.0

3h	00m	10ft.85
	10	.55
	20	.5
	30	.4
	40	.3
	50	.3
4	00	.3
	10	.3
	20	.4
	30	.5

\- - - -

H. W.

8	40	20.0
	50	.2
9	00	.55
	10	21.15
	20	.4
	30	.6
	40	.8
	50	22.0
10	00	.05
	10	.1
	20	.1
	30	.1
	40	.1
	50	.1
11	00	.0
	10	21.9

\- - - -

June 22 A. M.

L. W.

5	00	11.3
	10	.1
	20	.1
	30	.1
	40	.2
	50	.3
6	00	.3

\- - - -

H. W.

11	00	18.7
	10	.6
	20	.5

\- - - -

P. M.

L. W.

4	30	10.6
	40	- - -
	50	.5
5	00	.5
	10	.5
	20	.7
	30	.8

\- - - -

H. W.

10h	40m	22ft.5
	50	.6
11	00	.6
	10	.7
	20	.7
	30	.7
	40	.6
	50	.5

\- - - -

June 23 A. M.

L. W.

4	30	11.9
	40	.6
	50	.3
5	00	.2
	10	.0
	20	10.85
	30	.8
	40	.7
	50	.7
6	00	.7
	10	.8
	20	.85
	30	.9

S.

H. W.

10	50	18.6
11	00	.8
	10	.85
	20	19.0
	30	.0
	40	.0
	50	.0
12	00	18.9
	10	.7

S.

P. M.

L. W.

4	50	10.6
5	00	.5
	10	.35
	20	.35
	30	.35
	40	.4
	50	.5
6	00	.6

S.

H. W.

10	50	21.85
11	00	22.05
	10	.3
	20	.45
	30	.6
	40	.7

Second series, 1861.—*Continued.*

June 23 P. M.
H. W.
11^{h} 50^{m} $22^{ft}.75$
0 00 .75
10 .75
- - - - - -
1 20 .1
S.

June 24 A. M.
L. W.
5 30 11.1
40 .0
50 10.85
6 00 .8
10 .7
20 .6
30 .6
40 .6
50 .6
7 00 .6
10 .7
20 .9
S.

H. W.
11 10 18.25
20 .5
30 .7
40 .9
50 19.0
12 00 .1
10 .2
20 .2
30 .2
40 .1
50 .0
1 00 18.9
S.

P. M.
L. W.
5 10 11.35
20 .2
30 10.95
40 .9
50 .8
6 00 .8
10 .8
20 .85
30 .9
40 11.0
S.

H. W.
11 00 20.9
10 21.3
20 .65
30 22.0

11^{h} 40^{m} $22^{ft}.2$
50 .3
12 00 .5
10 .7
20 .8
30 .9
40 .9
50 .9
1 00 .8
10 .7
S.

June 25 A. M.
L. W.
6 20 11.2
30 .0
40 10.9
50 .8
7 00 .7
10 .7
20 .7
30 .85
40 .95
S.

H. W.
11 30 17.8
40 ...
50 18.25
12 00 .5
10 .7
20 .8
30 19.05
40 .2
50 .2
1 00 .25
10 .25
20 .2
30 .2
40 .1
50 18.95
R.
Heavy gale from S. W.

P. M.
L. W.
5 50 11.9
6 00 .8
10 .6
20 .5
30 .4
40 .3
50 .3
7 00 .3
10 .3
20 .4
30 .55
R.
Heavy gale from S. W.

June 26 A. M.
H. W.
0^{h} 00^{m} $21^{ft}.4$
10 .65
20 .9
30 22.0
40 .2
50 .35
1 00 .4
10 .5
20 .6
30 .6
40 .55
50 .4
R.
Heavy gale from S. W.

L. W.
6 10 12.9
20 .55
30 .3
40 11.9
50 .8
7 00 .5
10 .5
20 .3
30 .3
40 .05
50 .05
8 00 .1
10 .1
20 .2
30 .2
40 .3
50 .4
R.
Heavy gale from S. W.

P. M.
H. W.
0 30 18.1
40 .2
50 .4
1 00 .7
10 .7
20 .8
30 .9
40 19.0
50 .0
2 00 .0
10 .0
20 .0
30 18.8
K.
Heavy wind

L. W.
6 30 12.5
40 .3

6^{h} 50^{m} $12^{ft}.1$
7 00 .0
10 .0
20 .0
30 11.8
40 .8
50 .8
8 00 12.1
K.
Heavy wind.

June 27 A. M.
H. W.
1 00 21.4
10 .5
20 .6
30 .7
40 .9
50 .9
2 00 .9
10 22.0
20 .0
30 21.8
K.
Strong wind.

L. W.
7 10 12.4
20 .1
30 11.9
40 .7
50 .7
8 00 .5
10 .5
20 .4
30 .4
40 .4
50 .4
9 00 .4
10 .4
20 .7
K.

P. M
H. W.
1 00 17.9
10 18.0
20 .2
30 .3
40 .5
50 .65
2 00 .7
10 .8
20 .85
30 .9
40 .9
50 .9
3 00 .75
S.

L. W.
7^{h} 00^{m} $13^{ft}.25$
10 .1
20 12.95
30 .8
40 .7
50 .6
8 00 ......
10 .6
20 .6
30 .6
40 .7
50 .75
9 00 .9
S.

June 28 A. M.
H. W.
1 30 20.4
40 .7
50 .9
2 00 21.0
10 .1
20 .1
30 .1
40 .1
50 .05
3 00 20.95
S.

L. W.
7 30 13.0
40 12.8
50 .6
8 00 .35
10 .1
20 .0
30 11.9
40 .8
50 .8
9 00 .8
10 .8
20 .8
30 .8
40 .9
50 12.0
S.

P. M.
H. W.
2 00 17.9
10 18.0
20 .1
30 .3
40 .4
50 .5
3 00 .55
10 .6
20 .6

Second series, 1861.—*Continued.*

June 28 P. M.

H. W.

3h	30m	18ft.6
	40	.5
	50	.4

R.

L. W.

8	00	13.6
	10	......
	20	.4
	30	.35
	40	.3
	50	.25
9	00	.25
	10	.25
	20	.3
	30	.35

R.

June 29 A. M.

H. W.

2	00	16.4
	10	.5
	20	.5
	30	.55
	40	.55
	50	.55
3	00	.55
	......	
	10	20.8
	20	.8
	30	.7

Uncertain. Guy caught and not discovered till too late.

R.

L. W.

8	30	13.8
	40	.65
	50	.5
9	00	.4
	10	.25
	20	.2
	30	.1
	40	.1
	50	.1
10	00	.1
	10	.1
	20	.3

K.

P. M.

H. W.

2	30	18.5
	40	.8
	50	.9
3h	00m	19ft.0
	10	.2
	20	.3
	30	.4
	40	.4
	50	.45
4	00	.45
	10	.45
	20	.5
	30	.6

K.

L. W.

8	50	15.5
9	00	.4
	10	.35
	20	.3
	30	.2
	40	.2
	50	.2
10	00	.2
	10	.3
	20	.5

K.

June 30 A. M.

H. W.

3	40	20.2
	50	.4
4	00	.6
	10	.6
	20	.65
	30	.7
	40	.7
	50	.6
5	00	.6
	10	.4

K.

L. W.

9	20	14.1
	30	13.95
	40	.85
	50	.75
10	00	.6
	10	.6
	20	.6
	30	.6
	40	.6
	50	.6
11	00	.7
	10	.75
	20	.8

S.

P. M.

H. W.

3	20	18.5
	30	.65
3h	40m	18ft.75
	50	.85
4	00	.9
	10	19.15
	20	.2
	30	.2
	40	.2
	50	.3
5	00	.4
	10	.4
	20	.35
	30	.35
	40	.3
	50	.25

S.

L. W.

9	40	16.1
	50	.0
10	00	15.9
	10	.8
	20	.8
	30	.75
	40	.7
	50	.7
11	00	.7
	10	.7
	20	.8
	30	.85

S.

July 1 A. M.

H. W.

4	10	19.1
	20	.2
	30	.2
	40	.2
	50	.2
5	00	.2
	10	.1
	20	.1
	30	.0

S.

L. W.

10	00	14.5
	10	......
	20	.3
	30	.25
	40	.15
	50	.05
11	00	.0
	10	.0
	20	.0
	30	.0
	40	.05
	50	.15

R.

P. M.

H. W.

4h	30m	18ft.9
	40	19.1
	50	.2
5	00	.3
	10	.5
	20	.6
	30	.65
	40	.7
	50	.75
6	00	.8
	10	.8
	20	.8
	30	.8
	40	.75
	50	.7
7	00	.65
	10	.6

S.

L. W.

10	30	16.7
	40	.7
	50	.65
11	00	.55
	10	.45
	20	.35
	30	.3
	40	.2
	50	.2
12	00	.1
	10	.1
	20	.1
	30	.05
	40	.05
	50	05
1	00	.1
	10	.2

R.

July 2 A. M.

H. W.

5	30	18.55
	40	.6
	50	.6
6	00	.6
	10	.6
	20	.5
	30	.45

R.

L. W.

11	50	14.2
12	00	.1
	10	.1
	20	.1
	30	.1
	40	.1
	50	.1
1h	00m	14ft.15
	10	.25

K.

P. M.

H. W.

5	40	19.4
	50	.5
6	00	.7
	10	.75
	20	.85
	30	.9
	40	.95
	50	20.0
7	00	.1
	10	.1
	20	.1
	30	.1
	40	.1
	50	.1
8	00	.1
	10	.05
	20	19.9

K.

L. W.

11	50	16.65
12	00	.5
	10	.4
	20	.45
	30	.3
	40	.3
	50	.1
1	00	.05
	10	.0
	20	.0
	30	.0
	40	.0
	50	.0
2	00	.0
	10	.1
	20	.25

K.

July 3 A. M.

H. W.

6	10	18.2
	20	.3
	30	.4
	40	.4
	50	.4
7	00	.4
	10	.4
	20	.4
	30	3
	40	.2

K.

Second series, 1861.—*Continued.*

July 3 P. M.		
L. W.		
0^{h}	00^{m}	$14^{ft}.6$
	10	.5
	20	.4
	30	.3
	40	.25
	50	.2
1	00	.15
	10	.1
	20	.1
	30	.1
	40	.1
	50	.15
2	00	.2
	10	.3
S.		
H. W.		
6	40	19.7
	50	.8
7	00	.9
	10	20.0
	20	.05
	30	.2
	40	.35
	50	.4
8	00	.45
	10	.5
	20	.5
	30	.5
	40	.5
	50	.45
9	00	.4
	10	.3
S.		
July 4 A. M.		
L. W.		
0	30	16.55
	40	.4
	50	.2
1	00	.05
	10	15.9
	20	.75
	30	.6
	40	.5
	50	.4
2	00	.25
	10	.2
	20	.15
	30	.0
	40	.0
	50	.0
3	00	.05
	10	.15
S.		

H. W.		
7^{h}	00^{m}	$17^{ft}.65$
	10	.75
	20	.8
	30	.9
	40	18.0
	50	.0
8	00	.0
	10	.0
	20	.0
	30	.0
	40	.0
	50	17.9
9	00	.8
S.		
P. M.		
L. W.		
1	00	14.05
	10	13.9
	20	.8
	30	.65
	40	.6
	50	.5
2	00	.45
	10	.5
	20	.5
	30	.5
	40	.6
R.		
H. W.		
7	30	19.9
	40	20.1
	50	.25
8	00	.4
	10	.55
	20	.7
	30	.8
	40	.9
	50	.9
9	00	.9
	10	.9
	20	.9
	30	.85
	40	.8
R.		
July 5 A. M.		
L. W.		
2	30	14.75
	40	.65
	50	.6
3	00	.5
	10	.4
	20	.4
	30	.4
	40	.4
	50	.4

4^{h}	00^{m}	$14^{ft}.4$
	10	.5
	20	.6
R.		
H. W.		
8	30	18.2
	40	.3
	50	.3
9	00	.3
	10	.3
	20	.3
	30	.25
	40	.2
	50	.0
K.		
P. M.		
L. W.		
2	30	13.3
	40	.25
	50	.2
3	00	.2
	10	.2
	20	.25
	30	.3
	40	.4
S.		
H. W.		
8	40	15.6
	50	......
9	00	.4
	10	.4
Guy caught		
	20	22.6
	30	.7
	40	.7
	50	.7
10	00	.7
	10	.6
	20	.5
S.		
July 6		
L. W.		
Not observed		
A. M.		
H. W.		
9	00	19.8
	10	20.0
	20	.1
	30	.1
	40	.1
	50	.15
10	00	.15
	10	.1
	20	.05
R.		

P. M.		
L. W.		
3^{h}	00^{m}	$14^{ft}.4$
	10	.3
	20	.2
	30	.2
	40	.2
	50	.2
4	00	.25
	10	.35
	20	.5
S.		
H. W.		
9	40	23.3
	50	.35
10	00	.4
	10	.4
	20	.4
	30	.4
	40	.4
	50	.35
11	00	.3
	10	.2
Doubtful, as the pole was covered		
S.		
July 7 A. M.		
L. W.		
3	40	14.9
	50	.85
4	00	.7
	10	.55
	20	.45
	30	.35
	40	.35
	50	.35
5	00	.35
	10	.35
	20	.4
	30	.5
R.		
H. W.		
9	30	19.95
	40	20.15
	50	.3
10	00	.35
	10	.4
	20	.4
	30	.4
	40	.4
	50	.4
11	00	.3
	10	.2
S.		

P. M.		
L. W.		
3^{h}	30^{m}	$13^{ft}.95$
	40	.8
	50	.7
4	00	.7
	10	.7
	20	.7
	30	.7
	40	.75
	50	.9
5	00	14.05
S.		
H. W.		
10	00	23.8
	10	.95
	20	24.2
	30	.25
	40	.3
	50	.3
11	00	.3
	10	.2
	20	.15
	30	23.95
S.		
July 8 A. M.		
L. W.		
4	00	14.75
	10	.5
	20	.35
	30	.15
	40	.05
	50	13.9
5	00	.8
	10	.7
	20	.7
	30	.7
	40	.8
	50	.95
S.		
H. W.		
10	30	20.5
	40	.6
	50	.65
11	00	.7
	10	.7
	20	.6
	30	.5
S.		
P. M.		
L. W.		
3	50	13.7
4	00	.55
	10	.4
	20	.3

Second series, 1861.—*Continued.*

July 8 P. M.

L. W.		
4^h	30^m	$13^{ft}.15$
	40	.1
	50	.05
5	00	.05
	10	.1
	20	.25
	30	.35
S.		
H. W.		
10	30	23.7
	40	.8
	50	.9
11	00	24.1
	10	.2
	20	.2
	30	.25
	40	.25
	50	.15
12	00	23.95
S.		

July 9 A. M.

L. W.		
5	00	13.4
	10	.2
	20	.1
	30	.0
	40	12.95
	50	.9
6	00	.9
	10	.95
	20	13.0
R.		
H. W.		
11^h	00^m	$20^{ft}.45$
	10	.5
	20	.6
	30	.6
	40	.6
	50	.6
12	00	.5
K.		
P. M.		
L. W.		
5	00	12.6
	10	.5
	20	.5
	30	.45
	40	.45
	50	.55
6	00	.65
S.		
H. W.		
11	10	23.6
	20	.7
	30	.9
	40	24.0
	50	.0
12	00	.0
	10	.0
	20	.0
	30	23.8
K.		

July 10 A. M.

L. W.		
5^h	20^m	$13^{ft}.9$
	30	.7
	40	.5
	50	.5
6	00	.5
	10	.65
S.		
H. W.		
11	30	21.0
	40	.1
	50	.2
12	00	.2
	10	.25
	20	.3
	30	.3
	40	.3
	50	.1
1	00	.0
S.		
P. M.		
L. W.		
5	30	13.3
	40	.2
	50	.1
6	00	.1
	10	.1
	20	.1
	30	.2
	40	.3
S.		
H. W.		
11^h	50^m	$24^{ft}.2$
12	00	.3
	10	.35
	20	.5
	30	.5
	40	.45
	50	.4
1	00	.3
S.		

July 11 A. M.

L. W.		
5	30	13.7
	40	.3
	50	.1
6	00	12.9
	10	.7
	20	.4
	30	.25
	40	.15
	50	.1
7	00	.1
	10	.1
	20	.2
	30	.3
	40	.4
S.		
H. W.		
11	50	20.5
12	00	.7
	10	.9
	20	21.0
	30	.1
	40	.1
12^h	50^m	$21^{ft}.2$
1	00	.2
	10	.15
	20	.1
R.		
P. M.		
L. W.		
6	20	13.0
	30	12.9
	40	.9
	50	.9
7	00	.9
	10	13.0
R.		

July 12 A. M.

H. W.		
0	30	23.4
	40	.5
	50	.6
1	00	.6
	10	.65
	20	.65
	30	.55
	40	.5
....		
L. W.		
7	00	12.2
	10	1
	20	.0
	30	.0
	40	.0
	50	.05
8	00	.1
....		

The times of the preceding record were taken from a watch set approximately to local mean solar time; the following comparisons between this watch and mean time chronometer No. 2007 were made for the purpose of obtaining the watch correction and rate.

Watch and Chronometer Comparisons for the correction of the times of the Tidal Record.

Date.	Watch.	Chronometer.	Date.	Watch.	Chronometer.
June 6	8^h 56^m 00^s	$= 1^h$ 43^m	June 28	2^h 18^m $41^s.5$ P. M.	$= 7^h$ 04^m
" 7	10 07 45.5 P. M.	2 55	" 30	8 33 35 A. M.	1 32
" 9	10 17 29 "	3 07	July 1	8 39 02 "	1 40
" 11	5 25 36 "	10 15	" 2	8 30 09 "	1 33
" 17	9 08 43.5 A. M.	2 11	" 3	8 34 22 "	1 39
" 19	8 40 29.5 "	1 46	" 4	8 51 51 "	1 58
" 20	8 02 29.2 "	1 09	" 6	9 04 00 "	2 14
" 21	8 48 20 "	1 56	" 7	8 34 24.5 "	1 47
" 25	8 40 23 "	1 35	" 8	8 40 02 "	1 55
	Watch stopped (before the 25th)		" 9	8 45 03 "	2 02
" 26	7 52 21 A. M.	0 43	" 10	8 13 57 "	1 33

The following resulting chronometer corrections (ΔT) of the eight day chronometer No. 2007, on Port Foulke mean time, is extracted from the discussion of the astronomical observations of the expedition (Part I).

June 7, 1861	$\Delta T =$	$-4^h\ 47^m\ 52^s$
July 10, 1861		$-4\ \ 47\ \ 15$
Hence daily rate	$\delta T =$	$+1^s.1$

With these data we find the corrections ΔT to the watch as follows:—

June 6,	$\Delta T = -0^m.9$	June 21,	$\Delta T = +20^m.1$	July 3,	$\Delta T = +17^m.2$
" 7,	-0.7	" 25,	$+7.1$	" 4,	$+18.7$
" 9,	$+1.7$	" 26,	$+3.2$	" 6,	$+22.7$
" 11,	$+1.6$	" 28,	-2.2	" 7,	$+25.3$
" 17,	$+14.6$	" 30,	$+11.0$	" 8,	$+27.7$
" 19,	$+17.9$	July 1,	$+13.6$	" 9,	$+29.6$
" 20,	$+18.9$	" 2,	$+15.4$	" 10,	$+31.8$

Average daily rate, June 6 to June 21 . . . $+1^m.4$
" " " June 30 to July 10 . . . $+2.1$

The preceding observations, taken at regular intervals near the time of each high and low water, generally suffice to fix the epoch of the highest and lowest level within five minutes. The readings appear quite regular, and are evidently but little affected by agitation of the surface against which the surrounding ice acted as a complete preventive. The mean time during which the same, highest or lowest, readings are recorded has been adopted for the epoch of high or low water, though in some cases a closer process has been attempted by considering the readings preceding and following. If the anterior and posterior slopes of the wave were the same, the average times of any two equal readings of height would give a closer determination; for instance, for low water, June 6 P. M., we have—

Reading 11.9 feet at				$3^h\ 50^m$
11.95 feet at	$3^h\ 35^m$ and	$4^h\ 10^m$	mean,	3 52
12.0 feet at	3 20	4 25	"	3 52
12.05 feet at	3 10	4 30	"	3 50
Adopted epoch . . .				3 51

On the other hand, if the shape of the wave is unsymmetrical, and this is the rule in our case, we find by attempting the above process that the successive times show a regular progression; for instance, the low water, June 7 A. M.—

Reading 12.1 feet at				$4^h\ 40^m$
12.15 feet at	$4^h\ 30^m$ and	$4^h\ 55^m$	mean,	4 42
12.2 feet at	4 25	5 10	"	4 47
12.25 feet at	4 20	5 20	"	4 50

Here we have to adopt $4^h\ 40^m$ as the epoch of low water.

A graphical process appears to be the best in all cases. Suppose the observations, taken at regular (or irregular) intervals, plotted by rectangular co-ordinates (times and corresponding heights), and a number of parallel level lines ruled across the crest (or trough) of the wave. Halving the length of each of these lines (within the curve) and uniting their middle points by a curve, that curve will generally intersect the wave nearly at right angles, and indicate the highest (or lowest) point in it.

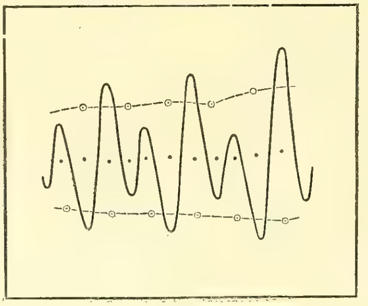
The second part of Table I contains the observed times of high and low water, corrected for error of watch. The adopted watch corrections for June 22d, 23d, and 24th, were +18, +15, and +12^{m} respectively. For June 29th, the correction was +10^{m}: and for July 11th and 12th, +33 and +34^{m}.

Determination of the Mean Level of the Sea.

An inquiry into the reading of the mean level of the sea is important in more than one aspect; first, we may test the value of our observations with respect to the invariability of the zero point of the scale which may change from the following causes: a gradual lengthening of the rope; a gradual shifting of the weight by which it is anchored on the *sloping* bottom by the action of currents, or by ice, and possibly also by a motion in the ice-field itself upon which the tidal apparatus rested, and finally by a change in the position of the weight after the rope had been taken up for repairs and was replaced. Secondly, by marking, at certain epochs, the half-tide level of the sea, which is subject to smaller fluctuations than either the average level of high water or the average level of low water, we may ascertain any relative change in the level of sea and land produced by geological causes. All levelling operations must also be referred to a certain tidal level. Thirdly, since theory points out certain fluctuations in the tidal level of the ocean due to the differential action of the sun and moon, their study and comparison with observation will bring them to a practical test. There are other interesting questions connected with the subject of our inquiry, namely, the effect upon the level of the sea, of a change in the atmospheric pressure as indicated by the readings of the barometer, and also the effect of the wind, with respect to direction, duration, and strength, upon the average height of the sea. The change of the sea level for a given rise or fall of the barometer has only been ascertained for a few places, and the measures fail to show a satisfactory agreement. The effect of the wind is of an entirely local character.

The mean, or more properly the half-tide level, is the one to which all heights should be referred; on the average, therefore, we will have at high tide an equal sectional area of water above, and at low tide an equal sectional area of deficiency. Owing to the daily inequality and the half-monthly inequality, which have to be eliminated, the following process for finding the half-tide level was employed.

Diagram A.



Referring to the annexed diagram (A) to illustrate the numerical method, the mean reading of two successive high waters is taken and placed opposite the reading of the intermediate low water (see series of upper circles in diagram), next the mean of these successive values is placed opposite the intermediate high water. In like manner the mean of two successive low waters is taken and placed opposite the intermediate high water (see series of lower circles in diagram), and their means again are taken; we thus obtain on each horizontal line two values, one high the other low, exactly corresponding in epoch, the mean of which is that of the half-tide level as set out in the last column, thus:—

Date.	Phase.	Readings.	Means.		Means.		Half tide level.
1861. July 2	L.	16.0					
" "	H.	18.6			15.05		
" "	L.	14.1	19.35			15.05	17ft.17
" "	H.	20.1		19.30	15.05		17.17
" 3	L.	16.0	19.25			15.05	17.15
" "	H.	18.4		19.35	15.05		17.20
" "	L.	14.1	19.45			14.80	17.13
" "	H.	20.5		19.35	14.55		16.95
" 4	L.	15.0	19.25			14.37	16.81
" "	H.	18.0			14.20		
" "	L.	13.4	etc.				

The following table contains the date, time of high or low water, and corresponding height (corrected if necessary in accordance with preceding remarks), and the half-tide level as made out by the above process; the remaining columns contain the moon's declination at noon of each day, also the moon's parallax for the same epoch, together with the atmospheric pressure (reduced to the temperature 32° Fah., and the prevailing direction and force of the wind during each day.

Table I.—Observed times and heights of high and low waters at Port Foulke, latitude 78° 17′.6, longitude $4^h\ 52^m\ 0^s$ west of Greenwich. Also the corresponding half-tide level, the moon's declination, the moon's parallax, the atmospheric pressure (at the temperature of the freezing point of water), and the true direction and force of the wind.

Series I. November and December, 1860.										
Date.	High or low tide.	Observed mean time.	Morning or afternoon.	Observed height in feet.	Deduced half-tide level.	Moon's declination.	Moon's paral'x.	Atmos. press.	Direction of wind.	Force of wind.
Nov. 17	H.	$2^h\ 25^m$	A.	16.4	- - - -	—21°.0	56′.4	29in.7	calm	
"	L.	9 05	A.	8.2	- - - -					
18	H.	2 50	M.	13.6	11.85					
"	L.	9 30	M.	9.6	11.80	—17.2	55.7	29.9	N. E.	3
"	H.	3 25	A.	15.6	- - - -					
"	L.	10 00	A.	8.6	- - - -					
19	H.	- - - -	M.	- - -	- - - -					
"	L.	- - - -	M.	- - -	- - - -	—12.6	55.0	29.8	N. E.	4
"	H.	4 30	A.	14.7	- - - -					
"	L.	10 15	A.	7.7	- - - -					
20	H.	4 45	M.	12.0	- - - -					
"	L.	- - - -	M.	- - -	- - - -	—7.7	54.6	29.9	N. E.	1
"	H.	- - - -	A.	- - -	- - - -					
"	L.	10 45	A.	8.1	- - - -					

Series I. November and December, 1860.—*Continued.*

Date.	High or low tide.	Observed mean time.	Morning or afternoon.	Observed height in feet.	Deduced half-tide level.	Moon's declination.	Moon's paral'x.	Atmos. press.	Direction of wind.	Force of wind
Nov. 21	H.	- - - -	M.	- - -	- - - -					
"	L.	11h 50m	M.	9.7	- - - -	—2°.6	54'.3	30in.1	calm	
"	H.	5 20	A.	13.3	- - - -					
22	L.	0 25	M.	7.7	11.03					
"	H.	7 25	M.	13.4	11.11	+2.5	54.1	29.9	N. E.	7
"	L.	0 30	A.	9.7	11.26					
"	H.	7 15	A.	14.0	11.42					
23	L.	1 15	M.	8.2	11.51					
"	H.	8 00?	M.	14.2	11.50	+7.6	54.2	30.0	N. E.	7
"	L.	2 30	A.	9.6	11.44					
"	H.	7 30	A.	14.0	11.55					
24	L.	2 15	M.	7.7	11.61					
"	H.	9 25	M.	15.6	11.51	+12.4	54.3	30.1	N. E.	2
"	L.	3 30	A.	8.7	- - - -					
"	H.	8 10	A.	14.1	- - - -					
25	L.	- - - -	M.	- - -	- - - -					
"	H.	- - - -	M.	- - -	- - - -	+16.9	54.7	30.7	calm	
"	L.	- - - -	A.	- - -	- - - -					
"	H.	- - - -	A.	- - -	- - - -					
26	L.	3 25	M.	6.6	- - - -					
"	H.	10 00	M.	15.6	- - - -	+20.7	55.1	30.5	N. E.	3
"	L.	4 15	A.	7.6	11.13					
"	H.	10 00	A.	14.8	11.42					
27	L.	4 00	M.	6.5	11.73					
"	H.	10 30	M.	18.0	11.77	+23.6	55.5	30.1	calm	
"	L.	4 40	A.	7.7	11.68					
"	H.	10 45	A.	15.0	11.62					
28	L.	4 35	M.	5.6	11.58					
"	H.	11 00	M.	18.4	11.46	+25.4	56.0	30.2	S. W.	4
"	L.	5 30	A.	7.0	11.47					
"	H.	10 55	A.	14.7	11.75					
29	L.	4 45	M.	6.0	12.26					
"	H.	11 40	M.	20.2	12.95	+25.9	56.5	30.2	N. E.	2
"	L.	6 45	A.	9.3	13.71					
30	H.	0 30	M.	17.9	14.15					
"	L.	5 30	M.	8.9	14.26	+25.0	57.0	29.9	calm	
"	H.	0 15	A.	20.8	14.18					
"	L.	6 30	A.	9.6	14.10					
Dec. 1	H.	1 00	M.	17.0	14.03					
"	L.	6 30	M.	9.1	13.88	+22.6	57.5	30.3	S. W.	8
"	H.	0 45	A.	20.1	13.76					
"	L.	7 40	A.	9.1	13.68					
2	H.	1 00	M.	16.5	13.62					
"	L.	6 45	M.	9.0	13.52	+19.0	57.9	30.4	calm	
"	H.	1 30	A.	19.7	13.46					
"	L.	8 00	A.	8.8	13.47					
3	H.	2 10	M.	16.2	13.38					
"	L.	7 30	M.	9.4	13.27	+14.4	58.3	30.0	N. E.	4
"	H.	1 30	A.	18.6	13.21					
"	L.	8 10	A.	9.0	13.15					
4	H.	3 00?	M.	15.5 ?	13.35					
"	L.	8 15	M.	9.6	13.66	+8.9	58.7	29.7	calm	
"	H.	3 00	A.	20.0	13.92					
"	L.	10 10	A.	10.1	14.33					
5	H.	4 30	M.	16.5	14.35					
"	L.	9 45	M.	11.9	14.06	+3.0	59.1	29.7	N. E.	3
"	H.	4 35	A.	17.8 ?	14.16					
"	L.	10 45	A.	10.0	14.32					

Series I. November and December, 1860.—*Continued.*

Date.	High or low tide.	Observed Mean time.	Morning or afternoon.	Observed height in feet.	Deduced half-tide level.	Moon's declination.	Moon's paral'x.	Atmos. press.	Direction of wind.	Force of wind.
Dec. 6	H.	4^h 45^m	M.	17.4	14.33					
"	L.	10 55	M.	12.3	14.17	—3°.2	59′.3	$29^{in}.8$	N. E.	7
"	H.	6 35	A.	17.5	13.96					
"	L.	11 15	A.	9.0	13.91					
7	H.	6 55	M.	16.7	13.93					
"	L.	0 15	A.	12.6	13.98	—9.3	59.5	29.8	N. E.	7
"	H.	6 40	A.	17.3	14.11					
8	L.	0 30	M.	9.2	14.17					
"	H.	7 30	M.	18.0	14.08	—14.9	59.6	29 8	N. E.	8
"	L.	1 45	A.	11.8	13.96					
"	H.	7 30	A.	17.3	13.95					
9	L.	3 00	M.	8.3	13.72					
"	H.	8 40	M.	18.8	13.30	—19.7	59.6	29.7	N. E.	8
"	L.	2 30	A.	9.2	13.30					
"	H.	8 45	A.	16.5	13.55					
10	L.	2 30	M.	9.1	13.92					
"	H.	9 15	M.	20.0	- - - -	—23.3	59.3	29.6	N. E.	8
"	L.	3 15	A.	11.0	- - - -					
"	H.	- - - -	A.	- - -	- - - -					
11	L.	- - - -	M.	- - -	- - - -					
"	H.	- - - -	M.	- - -	- - - -	—25.4	59.0	29.8	N. E.	4
"	L.	4 30	A.	12.1	- - - -					
"	H.	10 30	A.	19.7	- - - -					
12	L.	4 30	M.	11.4	16.52					
"	H.	11 00	M.	23.0	16.50	—25.9	58.4	30.2	N. E.	1
"	L.	5 15	A.	11.9	16.45					
"	H.	11 15	A.	19.7	16.40					
13	L.	5 00	M.	11.0	16.39					
"	H.	11 15	M.	23.0	16.37	—24.7	57.8	30.1	N. E.	6
"	L.	5 30	A.	11.8	16.46					
"	H.	12 00	A.	19.7	16.65					
14	L.	6 00	M.	11.7	16.73					
"	H.	0 15	A.	23.8	16.72	—22.2	57.0	29.9	calm	
"	L.	6 45	A.	11.7	16.73					
15	H.	0 45	M.	19.7	16.65					
"	L.	7 00	M.	11.8	16.58	—18.6	56.3	29.7	N. E.	4
"	H.	1 00	A.	23.0	16.56					
"	L.	7 15	A.	12.0	16.56					
16	H.	1 45	M.	19.2	16.60					
"	L.	7 15	M.	12.3	16.67	—14.2	55.6	29.4	N. E.	5
"	H.	2 00	A.	22.8	16.83					
"	L.	8 00	A.	12.8	- - - -					
17	H.	1 45	M.	19.7	- - - -					
"	L.	- - - -	M.	- - -	- - - -	—9.3	55.1	29.6	calm	
"	H.	2 30	A.	22.1	- - - -					
"	L.	9 00	A.	12.7	- - - -					
18	H.	3 00	M.	18.6	16.50					
"	L.	9 00	M.	13.3	16.35	—4.2	54.6	30.0	calm	
"	H.	3 00?	A.	20.7	16.35					
"	L.	9 30	A.	12.9	16.41					
19	H.	3 45	M.	18.4	16.45					
"	L.	9 30?	M.	14.0?	16.42	+0.9	54.3	30.1	variable	3
"	H.	3 30?	A.	20.2?	16.42					
"	L.	10 15	A.	13.3	16.50					
20	H.	4 45	M.	18.0	16.45					
"	L.	10 30	M.	15.0	16.21	+6.1	54.2	30.3	S. W.	6
"	H.	5 15	A.	18.8	- - - -					
"	L.	11 00	A.	12.8	- - - -					

Date.	High or low tide.	Observed mean time.	Morning or afternoon.	Observed height in feet.	Deduced half-tide level.	Moon's declination.	Moon's paral'x.	Atmos. press.	Direction of wind.	Force of wind.
Series I. November and December, 1860.—*Continued.*										
Dec. 21	H.	- - - - -	M.	- - -	- - - -					
"	L.	11^h 00^m	M.	15.1	- - - -	+11°.0	54'.3	$30^{in}.6$	calm	
"	H.	5 00	A.	18.0	- - - -					
"	L.	11 45	A.	13.2	16.14					
22	H.	6 45	M.	18.2	16.06					
"	L.	1 00	A.	15.2	15.98	+15.5	54.5	30.5	calm	
"	H.	7 00	A.	17.3	16.07					
23	L.	0 45	M.	13.2	16.15					
"	H.	8 00	M.	19.0	16.23	+19.5	54.9	30.3	calm	
"	L.	1 30	A.	15.0	- - - -					
"	H.	7 30	A.	18.2	- - - -					
Series II. June and July, 1861.										
June 6	H.	10 09	M.	17.85	- - - -					
"	L.	3 50	A.	11.95	- - - -	+22.8	54.6	29.5	N. E.	3
"	H.	10 29	A.	20.8	15.70					
7	L.	4 39	M.	12.1	15.68					
"	H.	- - - - -	M.	18.1?	15.73	+24.5	54.9	29.6	N. E.	3
"	L.	4 29	A.	11.5	15.82					
"	H.	11 05	A.	21.65	15.90					
8	L.	5 35	M.	12.05	15.97					
"	H.	11 10	M.	18.72	16.04	+25.2	55.3	29.6	N. E.	1
"	L.	4 46	A.	11.5	16.11					
"	H.	11 36	A.	22.2	16.11					
9	L.	6 02	M.	12.0	16.14					
"	H.	11 37	M.	18.8	16.18	+24.5	55.8	29.5	calm	
"	L.	5 32	A.	11.65	16.21					
10	H.	0 12	M.	22.4	16.25					
"	L.	6 37	M.	12.0	16.32	+22.6	56.3	29.5	N. E.	2
"	H.	0 27	A.	19.1	16.40					
"	L.	6 12	A.	11.9	16.43					
11	H.	0 42	M.	22.8	16.40					
"	L.	7 13	M.	11.9	16.37	+19.5	56.8	29.7	calm	
"	H.	0 53	A.	18.9	16.30					
"	L.	6 44	A.	11.9	16.18					
12	H.	1 24	M.	22.2	16.11					
"	L.	8 00	M.	11.6	16.11	+15.3	57.3	29.8	S. W.	2
"	H.	1 45	A.	18.6	16.08					
"	L.	7 56	A.	12.2	16.06					
13	H.	2 01	M.	21.7	16.12					
"	L.	8 12	M.	11.9	16.25	+10.3	57.9	29.8	S. W.	1
"	H.	2 32	A.	18.75	16.32					
"	L.	8 13	A.	13.15	16.29					
14	H.	2 48	M.	21.35	16.27					
"	L.	9 04	M.	11.9	16.25	+4.7	58.4	29.9	S. W.	1
"	H.	3 29	A.	18.65	16.13					
"	L.	9 25	A.	13.05	16.02					
15	H.	3 40	M.	20.55	16.05					
"	L.	10 16	M.	11.8	16.21	—1.1	58.9	29.9	S. W.	2
"	H.	4 26	A.	19.0	16.35					
"	L.	10 17	A.	14.0	- - - -					
16	H.	4 07	M.	20.7	- - - -					
"	L.	- - - - -	M.	- - - -	- - - -	—7.0	59.3	29.7	S. W.	7
"	H.	- - - - -	A.	- - - -	- - - -					
"	L.	- - - - -	A.	- - - -	- - - -					

Series II. June and July, 1861.—*Continued.*

Date.	High or low tide.	Observed mean time.	Morning or afternoon.	Observed height in feet.	Deduced half-tide level.	Moon's declination.	Moon's paral'x.	Atmos. press.	Direction of wind.	Force of wind.
June 17	H.	-----	M.	----	----					
"	L.	-----	A.	----	----	—12°.6	59′.7	$30^{in}.0$	S. W.	7
"	H.	6^h 35^m	A.	20.75	----					
18	L.	0 25	M.	14.1	----					
"	H.	7 01	M.	19.0	16.52	—17.6	59.9	29.9	S. W.	5
"	L.	0 46	A.	12.3	16.48					
"	H.	7 57	A.	20.65	16.47					
19	L.	1 52	M.	13.9	16.48					
"	H.	7 52	M.	19.1	16.61	—21.6	60.0	29.7	S. W.	5
"	L.	1 38	A.	12.3	----					
"	H.	8 53	A.	21.65	----					
20	L.	-----	M.	----	----					
"	H.	8 54	M.	19.05	----	—24.2	60.0	29.8	S. W.	2
"	L.	2 34	A.	12.45	----					
"	H.	9 44	A.	21.7	16.34					
21	L.	3 20	M.	12.5	16.00					
"	H.	9 50	M.	18.4	15.77	—25.2	59.7	29.9	calm	
"	L.	4 15	A.	10.3	15.68					
"	H.	10 50	A.	22.1	15.58					
22	L.	5 40	M.	11.3	15.65					
"	H.	-----	M.	18.8 ?	15.75	—24.4	59.2	29.9	S. W.	1
"	L.	5 18	A.	10.5	15.75					
"	H.	11 37	A.	22.7	15.70					
23	L.	6 06	M.	10.7	15.70					
"	H.	11 50	M.	19.0	15.70	—22.2	58.5	29.8	variable	1
"	L.	5 34	A.	10.35	15.69					
24	H.	0 13	M.	22.75	15.70					
"	L.	6 52	M.	10.6	15.78	—18.7	57.7	29.6	variable	1
"	H.	0 31	A.	19.2	15.85					
"	L.	6 10	A.	10.8	15.89					
25	H.	0 48	M.	22.9	15.90					
"	L.	7 17	M.	10.7	15.97	—14.3	57.0	29.5	S. W.	7
"	H.	1 12	A.	19.25	16.00					
"	L.	7 01	A.	11.3	16.00					
26	H.	1 30	M.	22.6	16.01					
"	L.	7 49	M.	11.05	16.05	—9.4	56.2	29.6	S. W.	7
"	H.	2 03	A.	19.0	16.03					
"	L.	7 43	A.	11.8	16.00					
27	H.	2 17	M.	22.0	16.03					
"	L.	8 46	M.	11.4	16.12	—4.2	55.5	29.5	S. W.	5
"	H.	2 40	A.	18.9	16.11					
"	L.	8 10	A.	12.6	16.00					
28	H.	2 24	M.	21.1	16.06					
"	L.	9 03	M.	11.8	16.11	+0.9	54.9	29.4	calm	
"	H.	3 18	A.	18.6	16.15					
"	L.	8 58	A.	13.25	16.27					
29	H.	3 19?	M.	20.8	16.54					
"	L.	9 59	M.	13.1	16.89	+6.1	54.5	29.4	calm	
"	H.	4 10	A.	19.45	17.12					
"	L.	9 55	A.	15.2	17.17					
30	H.	4 46	M.	20.7	17.23					
"	L.	10 36	M.	13.6	17.28	+10.8	54.3	29.4	calm	
"	H.	5 16	A.	19.4	17.16					
"	L.	11 07	A.	15.7	17.02					
July 1	H.	4 52	M.	19.2	17.12					
"	L.	11 28	M.	14.0	17.21	+15.2	54.2	29.3	S. W.	1
"	H.	6 29	A.	19.8	17.18					

Series II. June and July, 1861.—*Continued.*

Date.	High or low tide.	Observed mean time.	Morning or afternoon.	Observed height in feet.	Deduced half-tide level.	Moon's declination.	Moon's paral'x.	Atmos. press.	Direction of wind.	Force of wind.
July 2	L.	0^h 54^m	M.	16.05	17.12					
"	H.	6 10	M.	18.6	17.17	+19°.0	54′.3	$29^{in}.4$	calm	
"	L.	0 40	A.	14.1	17.20					
"	H.	7 46	A.	20.1	17.17					
3	L.	1 51	M.	16.0	17.15					
"	H.	7 12	M.	18.4	17.20	+22.0	54.5	29.4	calm	
"	L.	1 42	A.	14.1	17.12					
"	H.	8 42	A.	20.5	16.95					
4	L.	2 58	M.	15.0	16.82					
"	H.	8 28	M.	18.0	16.78	+24.2	54.9	29.7	S. W.	1
"	L.	2 24	A.	13.45	16.76					
"	H.	9 19	A.	20.9	16.72					
5	L.	3 55	M.	14.4	16.73					
"	H.	9 20	M.	18.3	16.92	+25.1	55.4	29.6	variable	2
"	L.	3 21	A.	13.2	- - - -					
"	H.	10 06	A.	22.7	- - - -					
6	L.	- - - - - -	M.	- - - -	- - - -					
"	H.	10 17	M.	20.15	- - - -	+24.9	55.9	29.4	N. E.	1
"	L.	3 58	A.	14.2	- - - -					
"	H.	10 43?	A.	23.4 ?	18.05					
7	L.	5 14	M.	14.35	18.02					
"	H.	10 54	M.	20.4	18.07	+23.3	56.5	29.6	calm	
"	L.	4 35	A.	13.7	18.10					
"	H.	11 16	A.	24.3	18.06					
8	L.	5 47	M.	13.7	18.01					
"	H.	11 33	M.	20.7	17.93	+20.4	57.0	29.7	variable	1
"	L.	5 23	A.	13.05	17.83					
9	H.	0 04	M.	24.25	17.71					
"	L.	6 24	M.	12.9	17.62	+16.4	57.6	29.9	N. E.	1
"	H.	0 05	A.	20.6	17.51					
"	L.	6 05	A.	12.45	17.56					
10	H.	0 31	M.	24.0	17.72					
"	L.	6 21	M.	13.5	17.89	+11 6	58.1	29.6	variable	3
"	H.	1 02	A.	21.3	18.03					
"	L.	6 37	A.	13.1	17.92					
11	H.	0 58	M.	24.5	17.74					
"	L.	7 31	M.	12.1	17.70	+6.0	58.5	29.9	S. W.	1
"	H.	1 28	A.	21.2	17.56					
"	L.	7 19	A.	12.9	17.44					
12	H.	1 49	M.	23.65	- - - -					
"	L.	8 04	M.	12.0	- - - -	+0.2	58.8	29.7	N. E.	1

If we now unite the four (generally) values for half-tide level of each day into a mean, we find the following daily results:—

Series I. 1860.			Series II. 1861.		
	Half-tide.	☾'s declination.		Half-tide.	☾'s declination.
November 17	- - - -	—21°.0	June 6	15ft.70	+22°.8
" 18	11ft.82	—17.2	" 7	15.78	+24.5
" 19	- - - -	—12.6	" 8	16.06	+25.2
" 20	- - - -	— 7.7	" 9	16.18	+24.5
" 21	11.21	— 2.6	" 10	16.35	+22.6
" 22	11.50	+ 2.5	" 11	16.31	+19.5
" 23	11.56	+ 7.6	" 12	16.09	+15.3
" 24	- - - -	+12.4	" 13	16.24	+10.3
" 25	- - - -	+16.9	" 14	16.17	+ 4.7
" 26	11.28	+20.7	" 15	16.20	— 1.1
" 27	11.70	+23.6	" 16	- - - -	— 7.0
" 28	11.56	+25.4	" 17	- - - -	—12.6
" 29	12.97	+25.9	" 18	16.49	—17.6
" 30	14.20	+25.0	" 19	16.54	—21.6
December 1	13.84	+22.6	" 20	16.34	—24.2
" 2	13.52	+19.0	" 21	15.76	—25.2
" 3	13.25	+14.4	" 22	15.71	—24.4
" 4	13.81	+ 8.9	" 23	15.70	—22.2
" 5	14.22	+ 3.0	" 24	15.80	—18.7
" 6	14.09	— 3.2	" 25	15.97	—14.3
" 7	14.00	— 9.3	" 26	16.02	— 9.4
" 8	14.04	—14.9	" 27	16.06	— 4.2
" 9	13.47	—19.7	" 28	16.15	+ 0.9
" 10	13.92	—23.3	" 29	16.93	+ 6.1
" 11	- - - -	—25.4	" 30	17.17	+10.8
" 12	16.47	—25.9	July 1	17.17	+15.2
" 13	16.47	—24.7	" 2	17.17	+19.0
" 14	16.73	—22.2	" 3	17.11	+22.0
" 15	16.59	—18.6	" 4	16.77	+24.2
" 16	16.70	—14.2	" 5	16.82	+25.1
" 17	- - - -	— 9.3	" 6	18.05	+24.9
" 18	16.40	— 4.2	" 7	18.06	+23.3
" 19	16.45	+ 0.9	" 8	17.92	+20.4
" 20	16.33	+ 6.1	" 9	17.60	+16.4
" 21	16.14	+11.0	" 10	17.89	+11.6
" 22	16.04	+15.5	" 11	17.61	+ 6.0
" 23	16.19	+19.5	" 12	- - - -	+ 0.2

An examination of the figures makes it evident that the zero shifted between November 28th and 30th, from some unexplained cause, by about 2.4 feet, and again on the 4th and 10th of December by 0.7 and 2.5 feet respectively, on which dates the tide rope had been taken up and replaced. These displacements are all in the same direction, indicating deeper water. In the second series there are breaks between June 20th and 21st, between June 28th and 29th, and on July 6th, of —0.7, +0.9, and +1.2 foot respectively, all in consequence of a derangement of the apparatus as stated in the record. The breaking down of the apparatus on June 17th does not appear to have affected the mean level reading.

Variation in the Mean Level of the Sea.—In accordance with the equilibrium and wave theories (533) of "Tides and Waves," by G. B. Airy, Astronomer Royal,

Encyclopædia Metropolitana, the variation of the mean level of the sea depends upon the changes of the moon's and sun's declinations, but as the latter goes through its changes in half a year, and as the zero levels of our two series are disconnected, we can only examine the lunar effect, which can be expressed by $C \sin^2\delta$, where the constant C amounts to a few inches to be determined by observation. The constant C is greater in low and high latitudes, and very small in middle latitudes. The oscillation will go through its changes in half a lunation ($14\frac{3}{4}$ days), and we may expect high level at the greatest declination, *independent* of the sign, and low level when the moon is in the equator.

The breaks in our mean level readings, as examined above, sufficiently demonstrate the insufficiency of the accuracy of our observations for so delicate an inquiry as the variation in the mean level; in some portions of the series the dependence of this level upon the declination appears systematic, but is hidden in other portions by irregularities. In Series I the mean of three readings of the level for $\delta = 0$ (after applying the corrections indicated) is 16.67, and for $\delta = \pm 26°$ from two readings is 16.88 feet, range $2\frac{1}{2}$ inches; in series II the mean of three readings (after applying the corrections indicated) is the same (17.80 feet) for $\delta = 0$ and $\delta = \pm 25°$, on the average therefore we would only have between one and two inches of oscillation.

But few investigations into the variations of the mean level have been made, and more complete comparisons of observation and theory, on this point, are very desirable.

Effect of Changes in the Atmospheric Pressure upon the Tides.—Considering the short series of observations any result for the dependence of the changes of the height of the barometric column upon those of the sea level can only be a first approximation, the result deduced from the observations is nevertheless entitled to some confidence. The treatment adopted was the following:—

The mean levels, each day, and for each series independently, were grouped in two columns for days with barometer *below*, and for days with barometer *above* its average value (30.01 inches for Series I, and 29.65 inches for Series II). The corresponding difference from the average value was also set down, and then the mean of the whole series taken, thus:—

For Series I, average level $16^{ft}.7$, average depression of barometer $0^{in}.22$
" " 16.6, " elevation " 0.24
Or —1 inch of change of level for $0^{in}.46$ of change of barometer.

For Series II, average level $18^{ft}.0$, average depression of barometer $0^{in}.15$
" " 17.8, " elevation " 0.17
Or —2 inches of change of level for $0^{in}.32$ of change of barometer.

From the two series combined we obtain therefore a change of —3 inches for a change of $\frac{3}{4}$ inch (nearly) in the barometric column; in other words, a rise of one inch of the barometric column will be accompanied by a corresponding fall in the level of the water of four inches nearly.

This result is also affected by any *uncompensated* part, by reason of the short series of observations, of the effect of the variation in the mean level, and also of the effect of the wind.

Investigations made by different methods for a few places, give very discordant results; for London, Mr. Lubbock found 7 inches, for Bristol, Mr. Bunt found 13 inches, and Sir J C. Ross, in a late number of the Philosophical Transactions (for 1854, Part II), deduced from observations at Port Leopold, in latitude 74° N., longitude 91° W., nearly the same value as that given for Bristol, stating that the effect is nearly in the *inverse* ratio of the specific gravity of the two bodies (mercury and water).

The subject is open to further investigations, and considering that an increase or decrease of atmospheric pressure in any one place must necessarily be accompanied by currents restoring the disturbed equilibrium, the phenomenon would seem more complex than might at first be supposed.

Effect of the Wind upon the Mean Level of the Sea.—As this effect is of an entirely local character, the result will be of importance only in so far as it affects the local phenomena of the tides; in refined tidal discussions the effect of the wind must be eliminated, and for *predicted* tides the possible influence it may exert, specially when for spring or neap tides, may become a matter of grave interest. Looking over the columns of the wind record in Table I it appears that the prevailing wind is either N. E. or S. W.; there occur some calms and a few entries of variable winds.

Tabulating, for each series of observations separately, the mean level reading, referred to the same zero by application of the corrections given, for days of N. E. wind, for days of S. W. wind, and for days of calms (including variables), the following results were obtained:—

Series I. Mean level with N. E. wind 16.6 feet (15 observations), with calms 16.6 feet (10 observations), with S. W. wind 16.8 feet (3 observations).

Series II. Mean level with N. E. wind 17.5 feet (6 observations), with calms 18.0 feet (15 observations), with S. W. wind 17.9 feet (13 observations).

With consideration of the number of days of observation in each case, the effect of the wind appears very small, with N. E. wind the level is depressed a small fraction of a foot, and with a S. W. wind elevated by the same amount. A northeast wind blowing off the land, and a southwest wind blowing on it, would produce the effect as stated. Two causes operate *against* a considerable change in the level, first the open strait giving free passage to accumulated waters, to the northward or southward, and secondly, the protection of ice-fields, preventing the wind from acting on the surface of the sea.

We have seen that the effect upon the height of the tides produced either by the regular oscillation of the half-tide level, or by the irregular changes in the atmospheric pressure and the action of the winds, is sufficiently small at Port Foulke to be safely left out of consideration in our subsequent investigations; the corrections alone will be needed which refer all observations to the *same zero* of the height scale; they are for series I: Between November 17th and 28th, +5.6 feet; between November 30th and December 3d, +3.2 feet; between December 5th and 10th, +2.5 feet. For series II: Between June 6th and 20th, +1.4 foot; between June

21st and 28th, +2.1 feet; and between June 29th and July 5th, +1.2 foot. The mean level reading for Series I is 16.7, and for Series II 17.9 feet; these levels, however, are disconnected.

General Character of the Port Foulke Tides.—We find by the subsequent analysis of the two series of observations, with respect to the half-monthly and the diurnal inequalities, that their general character is very much the same as that exhibited by the Van Rensselaer Harbor tides, a result which was to be expected since the two localities are but 55 statute miles apart (following the sinuosities of the coast line), with no apparent special configuration of the shore which might exert an influence on the tidal feature. The establishment at Port Foulke is nearly half an hour less than that of Van Rensselaer Harbor, consistent with the northerly (and easterly) propagation of the tidal wave. The average range of the tide is almost exactly the same at the two places. There is at Port Foulke a considerable diurnal inequality which *almost* reaches, at certain times, that limit beyond which a single-day tide is produced; the diurnal inequality in the height of high water is *greater* than in the height of low water; these features of the diurnal inequality are also common to the two localities.

We shall now proceed with the special investigation of the inequalities commencing with that which runs through its period in half a month. For this purpose Table II has been prepared. The second column contains the time of the moon's transit over the Port Foulke meridian, interpolated from the American Nautical Almanac; the lower transit is distinguished by being placed between brackets. The epochs of high and low tides are taken from Table I. Mean time has been adopted throughout, as no special advantage can be derived from the use of apparent time for so short a series of observations. The transit of the moon given is that one which *immediately precedes* the time of high or low water; the lunitidal intervals are given accordingly; those within brackets depend upon the lower transit of the moon. The fact that various *anterior* positions of the moon are required for the explanation of various tidal inequalities justifies us in using, in a first investigation, the *preceding* transit; the subject will again be referred to in connection with the moon's parallactic and declination effects. The reason why no *one* anterior lunar epoch will answer, even for ports on the same coast and at no very great distance apart, must be sought for, I think, in the compound character of the wave, composed of *propagated* and *direct* effects, the velocity of the various parts being differently affected by the variations in the depth of the sea over which these waves pass.

Table II.—Time of the moon's upper and lower transit over the meridian of Port Foulke; time, height, and establishment of high and low water.

Series I. November and December, 1860.

Date.	Moon's upper and lower transit.	Time of		Lunitidal interval of		Height of	
		high water.	low water.	high water.	low water.	high water.	low water.
Nov. 17	(3^h 44^m)	- - - -	- - - -	- - - - - - -	- - - - - - -	- - - -	- - - -
"	4 10	2^h 25^m	9^h 05^m	(10^h 41^m)	(17^h 21^m)	22^{ft}.0	13^{ft}.8
18	(4 33)	2 50	9 30	10 40	17 20	19.2	15.2
"	4 57	3 25	10 00	(10 52)	(17 27)	21.2	14.2
19	(5 19)	- - - -	- - - - -	- - - - - - -	- - - - - -	- - -	- - - -
"	5 41	4 30	10 15	(11 11)	(16 56)	20.3	13.3
20	(6 02)	4 45	- - - - -	11 04	- - - - - -	17.6	- - - -
"	6 23	- - - -	10 45	- - - - - - -	(16 43)	- - -	13.7
21	(6 43)	- - - -	11 50	- - - - - - -	17 27	- - -	15.3
"	7 03	5 20		(10 37)		18.9	
22	(7 23)	7 25	0 25	12 22	(17 42)	19.0	13.3
"	7 43	7 15	0 30	(11 52)	17 27	19.6	15.3
23	(8 03)	8 00?	1 15	12 17?	(17 52)	19.8	13.8
"	8 23	7 30	2 30	(11 27)	18 47	19.6	15.2
24	(8 44)	9 25	2 15	13 02	(18 12)	21.2	13.3
"	9 06	8 10	3 30	(11 26)	19 07	19.7	14.3
25	(9 28)	- - - - -	- - - -	- - - - - -	- - - - -	- - -	- - - -
"	9 50	- - - - -	- - - -	- - - - - -	- - - - -	- - -	- - - -
26	(10 14)	10 00	3 25	12 10	(17 57)	21.2	12.2
"	10 38	10 00	4 15	(11 46)	18 25	20.4	13.2
27	(11 03)	10 30	4 00	11 52	(17 46)	23.6	12.1
"	11 29	10 45	4 40	(11 42)	18 02	20.6	13.3
28	(11 56)	11 00	4 35	11 31	(17 32)	24.0	11.2
"		10 55	5 30	(10 59)	18 01	20.3	12.6
29	0 24	11 40	4 45	11 16	(16 49)	24.6	11.6
"	(0 51)		6 45		18 21		12.5
30	1 19	0 30	5 30	(11 39)	(16 39)	21.1	12.1
"	(1 47)	0 15	6 30	10 56	17 11	24.0	12.8
Dec. 1	2 15	1 00	6 30	(11 13)	(16 43)	20.2	12.3
"	(2 42)	0 45	7 40	10 30	17 25	23.3	12.3
2	3 10	1 00	6 45	(10 18)	(16 03)	19.7	12.2
"	(3 36)	1 30	8 00	10 20	16 50	22.9	12.0
3	4 02	2 10	7 30	(10 34)	(15 54)	19.4	12.6
"	(4 27)	1 30	8 10	9 28	16 08	21.8	12.2
4	4 52	3 00?	8 15	(10 33?)	(15 48)	18.7?	12.5
"	(5 16)	3 00	10 10	10 08	17 18	22.5	12.6
5	5 41	4 30	9 45	(11 14)	(16 29)	19.0	14.4
"	(6 05)	4 35	10 45	10 54	17 04	20.3?	12.5
6	6 30	4 45	10 55	(10 40)	(16 50)	19.9	14.8
"	(6 54)	6 35	11 15	12 05	16 45	20.0	11.5
7	7 19	6 55		(12 01)		19.2	
"	(7 45)	6 40	0 15	11 21	(17 21)	19.8	15.1
8	8 11	7 30	0 30	(11 45)	17 11	20.5	11.7
"	(8 37)	7 30	1 45	11 19	(18 00)	19.8	14.3
9	9 04	8 40	3 00	(12 03)	18 49	21.3	10.8
"	(9 33)	8 45	2 30	11 41	(17 53)	19.0	11.7
10	10 02	9 15	2 30	(11 42)	17 26	22.5	11.6
"	(10 32)	- - - -	3 15	- - - - - - -	(17 42)	- - -	13.5
11	11 02	- - - -	- - - -	- - - - - - -	- - - - - -	- - -	- - - -
"	(11 32)	10 30	4 30	11 28	(17 58)	19.7	12.1
12		11 00	4 30	(11 28)	17 28	23.0	11.4
"	0 03	11 15	5 15	11 12	(17 43)	19.7	11.9

Series I. November and December, 1860.—*Continued.*

Date.	Moon's upper and lower transit.	Time of high water.	Time of low water.	Lunitidal interval of high water.	Lunitidal interval of low water.	Height of high water.	Height of low water.
Dec. 13	(0^h 33^m)	11^h 15^m	5^h 00^m	(10^h 42^m)	16^h 57^m	$23^{ft}.0$	$11^{ft}.0$
"	1 02		5 30		(16 57)		11.8
14	(1 30)	0 00	6 00	10 58	16 58	19.7	11.7
"	1 57	0 15	6 45	(10 45)	(17 15)	23.8	11.7
15	(2 22)	0 45	7 00	10 48	17 03	19.7	11.8
"	2 48	1 00	7 15	(10 38)	(16 53)	23.0	12.0
16	(3 11)	1 45	7 15	10 57	16 27	19.2	12.3
"	3 35	2 00	8 00	(10 49)	(16 49)	22.8	12.8
17	(3 56)	1 45	- - - - -	10 10	- - - - -	19.7	- - -
"	4 18	2 30	9 00	(10 34)	(17 04)	22.1	12.7
18	(4 38)	3 00	9 00	10 42	16 42	18.6	13.3
"	4 59	3 00?	9 30	(10 22)?	(16 52)	20.7	12.9
19	(5 15)	3 45	9 30?	10 46	16 31?	18.4	14.0?
"	5 39	3 30?	10 15	(10 15?)	(17 00)	20.2?	13.3
20	(5 59)	4 45	10 30	11 06	16 51	18.0	15.0
"	6 19	5 15	11 00	(11 16)	(17 01)	18.8	12.8
21	(6 40)	- - - - - -	11 00	- - - - -	16 41	- - - -	15.1
"	7 00	5 00	11 45	(10 20)	(17 05)	18.0	13 2
22	(7 22)	6 45		11 45		18.2	
"	7 43	7 00	1 00	(11 38)	18 00	17.3	15.2
23	(8 06)	8 00	0 45	12 17	(17 23)	19.0	13.2
"	3 30	7 30	1 30	(11 24)	17 47	18.2	15.0

Series II. June and July, 1861.

Date.	Moon's upper and lower transit.	Time of high water.	Time of low water.	Lunitidal interval of high water.	Lunitidal interval of low water.	Height of high water.	Height of low water.
June 5							
"	(9 58)						
6	10 22	10 09	- - - - -	(12 11)	- - - - -	19.3	- - -
"	(10 47)	10 29	3 50	12 07	(17 52)	22.2	13.3
7	11 12	- - - - -	4 39	- - - - -	18 17	19.5?	13.5
"	(11 38)	11 05	4 29	11 53	(17 42)	23.1	12.9
8		11 10	5 35	(11 32)	18 23	20.1	13.4
"	0 05	11 36	4 46	11 31	(17 08)	23.6	12.9
9	(0 31)	11 37	6 02	(11 06)	17 57	20.2	13.4
"	0 58		5 32		(17 01)		13.0
10	(1 24)	0 12	6 37	11 14	17 39	23.8	13.4
"	1 50	0 27	6 12	(11 03)	(16 48)	20.5	13.3
11	(2 16)	0 42	7 13	10 52	17 23	24.2	13.3
"	2 42	0 53	6 44	(10 37)	(16 28)	20.3	13.3
12	(3 07)	1 24	8 00	10 42	17 18	23.6	13.0
"	3 32	1 45	7 56	(10 38)	(16 49)	20.0	13.6
13	(3 56)	2 01	8 12	10 29	16 40	23.1	13.3
"	4 21	2 32	8 13	(10 36)	(16 17)	20.2	14.5
14	(4 45)	2 48	9 04	10 27	16 43	22.8	13.3
"	5 09	3 29	9 25	(10 44)	(16 40)	20.1	14.4
15	(5 33)	3 40	10 16	10 31	17 07	22.0	13.2
"	5 57	4 26	10 17	(10 53)	(16 44)	20.4	15.4
16	(6 21)	4 07	- - - - -	10 10	- - - - -	22.1	- - -
"	6 46	- - - - -	- - - - -	- - - - -	- - - - -	- - -	- - -
17	(7 12)	- - - - -	- - - - -	- - - - -	- - - - -	- - -	- - -
"	7 38	6 35		(11 23)		22.2	
18	(8 05)	7 01	0 25	11 23	(17 13)	20.4	15.5
"	8 33	7 57	0 46	(11 52)	17 08	22.1	13.7

Series II. June and July, 1861.—*Continued.*

Date.	Moon's upper and lower transit.	Time of		Lunitidal interval of		Height of	
		high water.	low water.	high water.	low water.	high water.	low water.
June 19	(9^{h} 03^{m})	7^{h} 52^{m}	1^{h} 52^{m}	11^{h} 19^{m}	(17^{h} 47^{m})	$20^{ft}.5$	$15^{ft}.3$
"	9 33	8 53	1 38	(11 50)	17 05	23.1	13.7
20	(10 03)	8 54	- - - -	11 21	- - - - -	20.5	- - -
"	10 34	9 44	2 34	(11 41)	17 01	23.8	13.8
21	(11 05)	9 50	3 20	11 16	(17 17)	20.5	14.6
"	11 37	10 50	4 15	(11 45)	17 41	24.2	12.4
22		- - - - -	5 40	- - - - - -	(18 35)	20.9?	13.4
"	(0 07)	11 37	5 18	(11 30)	17 41	24.8	12.6
23	0 38	11 50	6 06	11 12	(17 59)	21.1	12.8
"	(1 06)		5 34		16 56		12.4
24	1 35	0 13	6 52	(11 07)	(17 46)	24.9	12.7
"	(2 00)	0 31	6 10	10 56	16 35	21.3	12.9
25	2 26	0 48	7 17	(10 48)	(17 17)	25.0	12.8
"	(2 50)	1 12	7 01	10 46	16 35	21.4	13.4
26	3 14	1 30	7 49	(10 40)	(16 59)	24.7	13.1
"	(3 37)	2 03	7 43	10 49	16 29	21.1	13.9
27	4 00	2 17	8 46	(10 40)	(17 09)	24.1	13.5
"	(4 20)	2 40	8 10	10 40	16 10	21.0	14.7
28	4 40	2 24	9 03	(10 04)	(16 43)	23.2	13.9
"	(5 01)	3 18	8 58	10 38	16 18	20.7	15.3
29	5 22	3 19?	9 59	(10 18)?	(16 58)	22.5	14.6
"	(5 42)	4 10	9 55	10 48	16 33	20.7	16.4
30	6 03	4 46	10 36	(11 04)	(16 54)	21.9	14.8
"	(6 24)	5 16	11 07	11 13	17 04	20.6	16.9
July 1	6 45	4 52	11 28	(10 28)	(17 04)	20.4	15.2
"	(7 07)	6 29		11 44		21.0	
2	7 29	6 10	0 54	(11 03)	18 09	19.8	17.2
"	(7 52)	7 46	0 40	12 17	(17 33)	21.3	15.3
3	8 15	7 12	1 51	(11 20)	18 22	19.6	17.2
"	(8 40)	8 42	1 42	12 27	(17 50)	21.7	15.3
4	9 05	8 28	2 58	(11 48)	18 43	19.2	16.2
"	(9 30)	9 19	2 24	12 14	(17 44)	22.1	14.6
5	9 56	9 20	3 55	(11 50)	18 50	19.5	15.6
"	(10 23)	10 06	3 21	12 10	(17 51)	23.9	14.4
6	10 50	10 17	- - - -	(11 54)	- - - - -	21.4	- - -
"	(11 17)	10 43?	3 58	11 53?	(17 35)	23.4?	15.4
7	11 44	10 54	5 14	(11 37)	18 24	20.4	14.3
"		11 16	4 35	11 32	(17 18)	24.3	13.7
8	(0 10)	11 33	5 47	(11 23)	18 03	20.7	13.7
"	0 37		5 23		(17 13)		13.0
9	(1 02)	0 04	6 24	11 27	17 47	24.3	12.9
"	1 28	0 05	6 05	(11 03)	(17 03)	20.6	12.4
10	(1 53)	0 31	6 21	11 03	16 53	24.0	13.5
"	2 18	1 02	6 37	(11 09)	(16 44)	21.3	13.1
11	(2 42)	0 58	7 31	11 40	17 13	24.5	12.1
"	3 07	1 28	7 19	(10 46)	(16 37)	21.2	12.9
12	(3 31)	1 49	8 04	10 42	16 57	23.7	12.0
"	3 55	- - - - -	- - - -	- - - - -	- - - - -	- - - -	- - -

Half-monthly Inequality.—The theoretical formula for the half-monthly inequality *in time* is, according to the equilibrium theory,

$$\tan 2\theta' = -\frac{h \sin 2\phi}{h' + h \cos 2\phi}$$

where h and h' represent the elevations of the spheroid due to the sun and moon respectively, ϕ the angular distance of the moon from the sun, and θ' the angular distance of the pole of the spheroid (or of high water) from the moon's place. In reality, however, the pole of this spheroid follows the moon at a certain distance, the mean value λ' of which is known as the "mean establishment," and which corresponds to a distance of the sun and moon of $\phi—\alpha$ instead of ϕ. This retroposition of the tide, which is mostly the effect of friction, has been called the "age" of the tide.

The above formula, in conformity with the wave theory, then assumes the form

$$\tan 2(\theta' - \lambda') = -\frac{h \sin 2(\phi - \alpha)}{h' + h \cos 2(\phi - \alpha)}$$

the mean establishment λ', the ratio of the solar and lunar effect $\frac{h}{h'}$ and the angle of retardation α are to be determined from the observations.

The theoretical expression for the half-monthly inequality in *height* is, according to the equilibrium theory,

$$y = \sqrt{(h'^2 + h^2 + 2h' h \cos 2\phi)}$$

where y represents the height of the pole of the equilibrium spheroid above the undisturbed mean level of the surface, this expression must be changed, in accordance with the wave theory, into the following[1]

$$y = \sqrt{\left(h'^2 + h^2 + 2 h' h \cos 2(\phi - \alpha)\right)}$$

the values of h', h and α must be found from the observations.

In order to compare our observations with these theoretical expressions the lunitidal intervals and heights of Table II were first arranged according to the time of the moon's transit; the total number of observations being comparatively small, the results by the two series were at once united, for which purpose the heights of the second series were all diminished by 1.2 foot to reduce them to the same plane of reference. No distinction was made between upper and lower transits. For the high waters as well as for low waters twelve groups of lunitidal intervals and corresponding heights were formed, and the values of each group, extending over one hour, were united into a mean, of which process the following is an example:—

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[1] Art. (535) Tides and Waves. $\tan 2(\theta - \lambda) = -\frac{S'' \sin 2(\overline{m - s} - \alpha)}{M'' + S'' \cos 2(\overline{m - s} - \alpha)}$ and

$$y = \sqrt{\left(M'''^2 + 2 M''' S''' \cos 2(\overline{m - s} - \alpha) + S'''^2\right)}$$

For Moon's Transit between 2 and 3 hours. First Series.					
☾'s transit.	Lun. interval for high water.	Height of high water.	☾'s transit.	Lun. interval for low water.	Height of low water.
2^h 15^m	10^h 30^m	$23^{ft}.3$	2^h 15^m	17^h 25^m	$12^{ft}.3$
(2 42)	(10 18)	(19 7)	(2 42)	(16 03)	(12.2)
(2 22)	(10 38)	(23.0)	(2 22)	(16 53)	(12.0)
2 48	10 57	19.2	2 48	16 27	12.3
Second Series.					
(2 16)	(10 37)	(19.1)	(2 16)	(16 28)	(12.1)
2 42	10 42	22.4	2 42	17 18	11.8
(2 00)	(10 48)	(23.8)	(2 00)	(17 17)	(11.6)
2 26	10 46	20.2	2 26	16 35	12.2
(2 50)	(10 40)	(23.5)	(2 50)	(16 59)	(11.9)
2 18	10 40	23.3	2 18	17 13	10.9
(2 42)	(10 46)	(20.0)	(2 42)	(16 37)	(11.7)
Mean, 2 29	10 40	21.6	2 29	16 50	11.9

The greater the number of values the more will the *uncompensated* part of diurnal inequality, declination effect, and parallax effect, disappear from the mean results. No observation was rejected.

The following table contains the mean hourly values for the high waters and low waters:—

For high water.			Number of observations.	For low water.			Number of observations.
☾'s transit.	Lun. int'l.	Height.		☾'s transit.	Lun. int'l.	Height.	
0^h 27^m	11^h 17^m	$21^{ft}.7$	11	0^h 27^m	17^h 24^m	$11^{ft}.8$	11
1 29	10 59	21.3	12	1 29	17 02	11.9	12
2 29	10 40	21.6	11	2 29	16 50	11.9	11
3 29	10 35	21.2	12	3 28	16 45	12.5	11
4 28	10 28	20.2	13	4 28	16 31	13.3	13
5 30	10 50	19.7	13	5 27	16 52	13.6	11
6 30	11 09	19.3	8	6 26	17 10	14.3	11
7 26	11 45	19.3	13	7 26	17 44	14.2	13
8 22	11 49	19.8	10	8 21	18 10	13.1	8
9 30	11 54	20.4	9	9 30	17 53	12.8	8
10 29	11 47	20.9	8	10 29	17 51	12.6	9
11 28	11 33	21.2	11	11 25	17 42	11.9	11
Mean,	11 13.8	20.5			17 19.5	12.8	

From this and the preceding table we find:—

Height of average high water level . . . . 20.5 feet
Height of average low water level . . . . . . 12.8 feet

Hence average rise and fall of tide 7.7 feet; at Van Rensselaer Harbor this quantity was 7.9 feet.

Height of highest high water level	24.6 feet
Height of lowest high water level	17.3 feet

Hence extreme fluctuation in high water level 7.3 feet; at Van Rensselaer Harbor the corresponding quantity was 8.4 feet.

Height of highest low water level	16.0 feet
Height of lowest low water level	10.8 feet

Hence extreme fluctuation in low water level 5.2 feet; at Van Rensselaer Harbor the corresponding quantity was 9.0 feet.

The extreme fluctuation in the water level observed was 13.8 feet; at Van Rensselaer Harbor this quantity was 16.6 feet.

The mean establishments at the two places compare as follows:—

Mean establishment of high water at Port Foulke,	$11^h\ 13^m.8$	
Mean establishment of high water at Van Rensselaer Harbor,	11 43.3	Diff. $29^m.5$
Mean establishment of low water at Port Foulke,	17 19.5	
Mean establishment of low water at Van Rensselaer Harbor,	17 48.0	Diff. $28^m.5$

The determination of the constants in the formula for half-monthly inequality, *in time*, is as follows:—

For high water: By interpolation, the mean interval occurs at $0^h\ 38^m.4$, hence $\alpha = 9^\circ\ 36'$

For low water: By interpolation, the mean interval occurs at 0 42.0, hence $\alpha = 10\ \ 30$

For high water: By a graphical process the greatest range in the interval is $1^h\ 25^m = 21^\circ\ 15'$ its sine[1] is 0.3624

For low water: By a graphical process the greatest range in the interval is $1^h\ 26^m = 21^\circ\ 30'$ its sine is 0.3665

The mean establishment for high water $\lambda' = 11^h\ 13^m.8 = 168^\circ\ 27'$

The mean establishment for low water 17 19.5 $= 259\ \ 52\frac{1}{2}$

We have consequently the following expressions:—

From 131 observed high waters,

$$\tan 2\,(\theta' - 168^\circ\ 27') = -\frac{0.3624 \sin 2\,(\phi - 9^\circ\ 36')}{1 + 0.3624 \cos 2\,(\phi - 9^\circ\ 36')}$$

and from 129 observed low waters

$$\tan 2\,(\theta' - 259^\circ\ 52\tfrac{1}{2}') = -\frac{0.3665 \sin 2\,(\phi - 10^\circ\ 30')}{1 + 0.3665 \cos 2\,(\phi - 10^\circ\ 30')}$$

By means of these expressions the inequality *in time* has been computed, the agreement with observation is shown in the following table, also by the two diagrams in which the observed quantities are indicated by dots.

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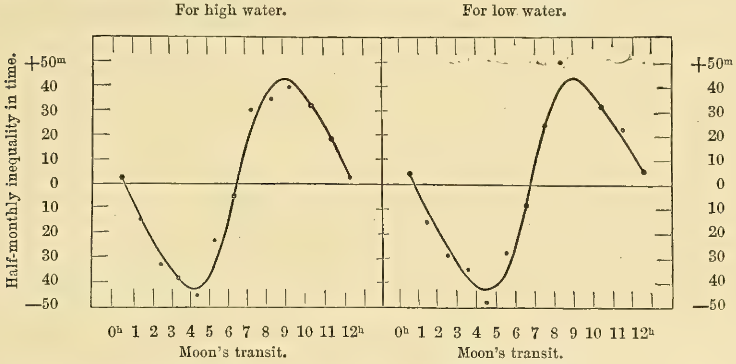
[1] In the manner in which $\frac{h}{h'}$ is deduced above it is preferable to use the sine instead of the tangent, as by Mr. Lubbock's process. See also Phil. Trans. 1836 (4th series of papers on Tides), by the Rev. W. Whewell.

Half-monthly inequality in time.							
In high water.				In low water.			
☾'s transit.	Observed.	Computed.	Difference.	☾'s transit.	Observed.	Computed.	Difference.
0^h 27^m	$+3^m$	$+3^m$	0^m	0^h 27^m	$+4^m$	$+4^m$	0^m
1 29	—15	—13	—2	1 29	—17	—12	— 5
2 29	—34	—28	—6	2 29	—29	—27	— 2
3 29	—39	—39	0	3 28	—35	—38	+ 3
4 28	—46	—42	—4	4 28	—48	—43	— 5
5 30	—24	—32	+8	5 27	—28	—35	+ 7
6 30	— 5	— 5	0	6 26	— 9	— 9	0
7 26	+31	+24	+7	7 26	+24	+23	+ 1
8 22	+35	+40	—5	8 21	+50	+40	+10
9 30	+40	+41	—1	9 30	+34	+41	— 7
10 29	+33	+32	+1	10 29	+32	+33	— 1
11 28	+19	+18	+1	11 25	+22	+20	+ 2

The comparison is shown to better advantage in the diagrams.



The range of this inequality amounts to 1^h 26^m for either the time of hign or of low water; this is about a normal value. At Van Rensselaer Harbor it amounted, however, to the unusually large value of 1^h 52^m.

The determination of the constants for the half-monthly inequality in *height* is as follows: First, for the retard; the epoch of the highest and lowest reading of high water differs from that of the syzygy and quadrature, on the average by 52^m, hence $\alpha = 13°$, similarly the epoch of the extreme readings of low water differs nearly 32^m, hence $\alpha = 9°$. Second, for the range; the inequality in the height of high water is 2.4 feet; half of this, or 1.2 is the coefficient: the inequality in the low water is 2.5 feet; its coefficient, therefore, 1.25. The mean of all the heights of high water being 20.55, and of all the heights of low water 12.83, we have at once the approximate expressions for the half-monthly inequality in height, for the high waters

$$y = 20.55 + 1.2 \cos 2 (\phi - 13°)$$

for the low water

$$y = 12.83 - 1.25 \cos 2 (\phi - 9°)$$

This form was also used by Mr. Whewell (Phil. Trans. 1834, Art. II) as a first approximation, and was applied by me to the Van Rensselaer Harbor tides. For short series it is quite sufficient, and in the present case the results found by it and by the more rigorous form given below hardly differ by as much as one inch in the extreme.

To find the ratio of the solar and lunar tide we have the greatest or spring tide range, 21.7 — 11.8 = 9.9 feet, and the least or neap tide range, 19.3 — 14.3 = 5.0 feet; the former being the sum, the latter the difference;

$$\text{hence the ratio } \frac{2.45}{7.45} = 0.329$$

For substitution in our formula given at the head of this article, we take for h the half of the difference between the highest and lowest high water, or the difference between the highest and lowest low water, which is 1.22, the corresponding h', by means of the above ratio, is 3.72, hence the expression

$$\sqrt{\left[3.72^2 + 1.22^2 + 2 \times 3.72 \times 1.22 \cos 2 (\phi - 13^\circ)\right]} \text{ and}$$

computing the inequality by this expression the mean of all the ordinates will be found = 3.81, which constant we subtract to obtain the inequality itself; we have therefore for high water the half-monthly inequality

$$y = \sqrt{\left[15.33 + 9.1 \cos 2 (\phi - 13^\circ)\right]} - 3.81$$

and for low water

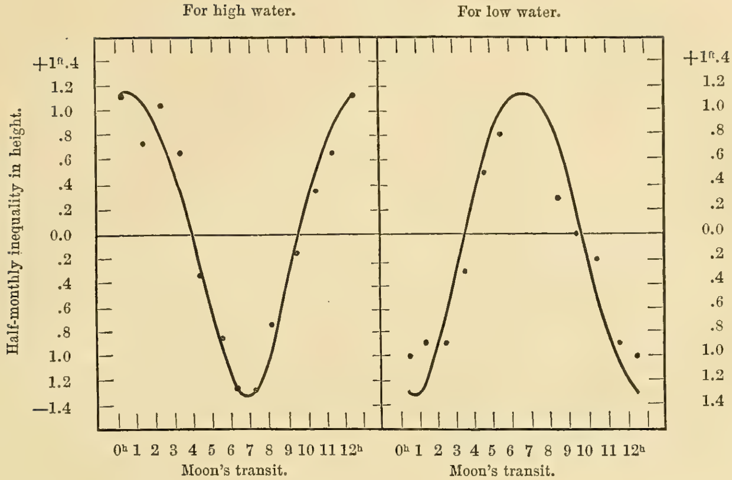
$$y = \sqrt{\left[15.33 - 9.1 \cos 2 (\phi - 9^\circ)\right]} - 3.83$$

The comparison between observed and computed heights is shown in the following table and by diagrams. The observed inequality was found by subtracting the mean of the whole from each single value. The results computed by the approximate formulæ are marked "app.;" those by the more rigorous formulæ are marked "rig."

Half-monthly inequality in height.

In high water.					In low water.				
☾'s tran.	Observed.	Computed app.	Computed rig.	Difference.	☾'s tran.	Observed.	Computed app.	Computed rig.	Difference.
0^h 27^m	+1ft.15	+1ft.17	+1ft.11	0ft.0	0^h 27^m	—1ft.0	—1ft.2	—1ft.3	+0ft.3
1 29	+0.75	+1.14	+1.09	—0.3	1 29	—0.9	—1.1	—1.1	+0.2
2 29	+1.05	+0.79	+0.81	+0.2	2 29	—0.9	—0.7	—0.6	—0.3
3 29	+0.65	+0.24	+0.33	+0.3	3 28	—0.3	—0.1	0.0	—0.3
4 28	—0.35	—0.37	—0.27	—0.1	4 28	+0.5	+0.5	+0.6	—0.1
5 30	—0.85	—0.91	—0.90	0.0	5 27	+0.8	+1.0	+0.9	—0.1
6 30	—1.25	—1.18	—1.28	0.0	6 26	+1.5	+1.3	+1.1	+0.4
7 26	—1.25	—1.15	—1.24	0.0	7 26	+1.4	+1.1	+1.0	+0.4
8 22	—0.75	—0.85	—0.83	+0.1	8 21	+0.3	+0.8	+0.7	—0.4
9 30	—0.15	—0.23	—0.12	0.0	9 30	0.0	+0.1	+0.1	—0.1
10 29	+0.35	+0.38	+0.46	—0.1	10 29	—0.2	—0.6	—0.5	+0.3
11 28	+0.65	+0.89	+0.89	—0.2	11 25	—0.9	—1.0	—1.0	+0.1

The low waters are not as well represented as the high waters.



The range for inequality is the same for high and low waters, whereas at Van Rensselaer Harbor the latter was considerably greater; the more rigorous expressions for the half-monthly inequality for this place are[1]

For high water $y = \sqrt{\left[18.25 + 12.0 \cos 2 (\phi - 15°)\right]} - 4.14$

For low water $y = \sqrt{\left[18.30 - 13.0 \cos 2 (\phi - 15°)\right]} - 4.12$

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[1] These equations should be substituted in the place of those given p. 71 (lines 3 and 5 from top) of the Van Rensselaer Harbor tidal discussion. The observed and computed inequality compare as follows :—

	For high water.			For low water.		
☾'s transit.	Observed.	Computed.	Difference.	Observed.	Computed.	Difference.
$0\frac{1}{2}^h$	+1ft.4	+1ft.3	—0ft.1	—1ft.3	—1ft.7	+0ft.4
$1\frac{1}{2}$	+1.3	+1.3	0.0	—1.5	—1.7	+0.2
$2\frac{1}{2}$	+1.1	+1.0	+0.1	—1.0	—1.1	+0.1
$3\frac{1}{2}$	+0.4	+0.5	—0.1	—0.7	—0.3	—0 4
$4\frac{1}{2}$	—0.3	—0.3	0.0	+0.5	+0.5	0.0
$5\frac{1}{2}$	—1.1	—1.0	—0.1	+1.4	+1.1	+0.3
$6\frac{1}{2}$	—1.6	—1.6	0.0	+1.7	+1.4	+0.3
$7\frac{1}{2}$	—1.3	—1.6	+0.3	+2.0	+1.4	+0.6
$8\frac{1}{2}$	—0.9	—1.0	+0.1	+1.1	+1.1	0.0
$9\frac{1}{2}$	—0.2	—0.2	0.0	+0.1	+0.5	—0.4
$10\frac{1}{2}$	+0.3	+0.5	—0.2	—0.8	—0.3	—0.5
$11\frac{1}{2}$	+0.9	+1.0	—0.1	—1.3	—1.1	—0.2

Comparing these remainders with those given on p. 71, and deduced from the approximate equations, it will be seen that the representation is equally good by either form.

depending on the ratio of solar to lunar tide $\frac{2.95}{7.85} = 0.376$, which is preferable to the value (0.367) given in the text (p. 71), the spring range being 10.8, and the neap range 4.9 feet, values which approximate closer to the Port Foulke results.

In the notation of Art.'s (536) to (540), Tides and Waves, we have from the time inequality, for Port Foulke $\frac{S''}{M''} = 0.364$, and from the height inequality $\frac{S'''}{M'''} = 0.329$; the heights generally give the smaller value, but that deduced from the times is theoretically the more correct one. The retard of the tide from the time-inequality is $\alpha = 10° \ 3'$, and from the height-inequality $\alpha = 11° \ 0'$, the latter is, theoretically, the preferable value. The average daily separation of the sun and moon is $48^{m}.8$; hence the time in which the moon moves through this angle or the age of the tide equals $\frac{11}{15 \times 49}$ or 0.9 of a day ($21\frac{1}{2}$ hours); by this interval the spring and neap tides follow the syzygy and quadrature respectively. The retard, as found at Port Foulke and Van Rensselaer Harbor, is comparatively small.

Effect of Changes of the Lunar Parallax on the Half-monthly Inequality.—From a short series of observations, like the one now under consideration, we can only deduce approximately the changes which the half-monthly inequality undergoes in consequence of variations in the lunar parallax, and the same remark applies to the changes produced by variations in the moon's declination. The method followed in this discussion is nearly the same for the parallactic and declination effects, and applies for high and low water and for times and heights. The luni-tidal intervals and corresponding heights were rearranged with reference to small and large values of the parallax; it is, however, not the parallax belonging to the epoch of high or low tide which was employed, but one anterior to that time, the retroposition depending on the retard of the tide as determined in the preceding article. As the average age amounts to nearly a day, the parallax preceding the effect by that interval was used in the tabulation. No distinction is required for upper or lower transits. The first group consists of intervals and heights for parallax between 54′ and 57′, the second for parallax between 57′ and 60′. The means being taken for each hour of the moon's transit, the following tables were obtained. The letter P stands for parallax; the inequality for the average parallax (57′) is added from the preceding investigation.

TABLE III.—Lunar-parallactic effect on the Half-monthly Inequality.

☾'s tran.	For high water.				For low water.			
	P = 55′.2		P = 58′.8		P = 55′.5		P = 58′.7	
	Lun. int'l.	Height.	Lun. int'l.	Height.	Lun. int'l.	Height.	Lun. int'l.	Height.
0^h 30^m	11^h 21^m	$21^{ft}.5$	11^h 13^m	$21^{ft}.9$	17^h 28^m	$12^{ft}.1$	17^h 19^m	$11^{ft}.5$
1 30	11 01	21.6	10 59	21.2	17 01	12.3	17 01	11.7
2 30	10 45	20.2	10 38	22.1	16 44	12.1	16 53	11.9
3 30	10 34	21.3	10 36	21.1	16 52	12.6	16 40	12.4
4 30	10 36	19.8	10 16	20.7	16 45	13.7	16 31	12.5
5 30	10 53	19.6	10 44	20.0	16 53	13.8	16 51	13.3
6 30	10 52	19.1	([1]10 52)	19.7	17 14	14.5	16 59	13.8
7 30	11 52	18.9	11 28	20.1	17 53	14.7	17 23	13.2
8 30	11 56	19.6	11 38	20.3	18 26	14.0	17 53	12.3
9 30	12 06	20.2	11 38	20.7	18 11	13.0	17 23	12.6
10 30	11 54	20.9	11 28	20.9	17 58	12.8	17 39	12.2
11 30	11 32	21.1	11 34	21.4	17 36	12.0	17 52	11.7
Mean,	11 17	20.3	11 05	20.8	17 25	13.1	17 12	12.4

We have therefore for the *non-periodical* effect of the parallax in time and height the values:—

High water mean establishment.	Lunar parallax.
11^h 17^m	55′
11 14	57
11 05	59

Represented by the formula
$11^h\ 14^m - 3^m\ (P - 57')$

Low water mean establishment.	Lunar parallax.
17^h 25^m	$55\frac{1}{2}'$
17 $19\frac{1}{2}$	57
17 12	$58\frac{3}{4}$

Represented by the formula
$17^h\ 19\frac{1}{2}^m - 4^m\ (P - 57')$

An *increase* of lunar parallax is followed by a *decrease* of the mean establishment for high as well as for low water.

Mean height of high water.	Lunar parallax.
$20^{ft}.3$	55′
20.55	57
20.8	59

An *increase* of the parallax is followed by an *increase* in the mean height, at a rate of $0^{ft}.13$ for 1′ of parallactic change.

Mean height of low water.	Lunar parallax.
$13^{ft}.1$	$55\frac{1}{2}'$
12.8	57
12.4	$58\frac{3}{4}$

An *increase* of the parallax is followed by a *decrease* in the mean height, at a rate of $0^{ft}.2$ for 1′ of parallactic change.

The range of the tide is consequently increased by $0^{ft}.3$ nearly for a parallactic increase of 1′.

For the *periodical* part we form the following table by subtraction of the mean values in Table III.

[1] Interpolated, number of observations insufficient.

	Inequality in high water.						Inequality in low water.					
☾'s tran.	P=55′	57′	59′	P=55′	57′	59′	P=55½′	57′	58¾′	P=55½′	57′	58¾′
$0^h\ 30^m$	$+\ 4^m$	$+\ 3^m$	$+\ 8^m$	$+1^{ft}.2$	$+1^{ft}.1$	$+1^{ft}.1$	$+\ 3^m$	$+\ 5^m$	$+\ 7^m$	$-1^{ft}.0$	$-1^{ft}.0$	$-0^{ft}.9$
1 30	—16	—15	— 6	+1.3	+0.8	+0.4	—24	—17	—11	—0.8	—0.9	—0.7
2 30	—32	—34	—27	—0.1	+1.0	+1.3	—41	—30	—19	—1.0	—0.9	—0.5
3 30	—43	—39	—29	+1.0	+0.7	+0.3	—33	—34	—32	—0.5	—0.3	0.0
4 30	—41	—46	—49	—0.5	—0.3	—0.1	—40	—49	—41	+0.6	+0.5	+0.1
5 30	—24	—24	—21	—0.7	—0.9	—0.8	—32	—27	—21	+0.7	+0.8	+0.9
6 30	—25	— 5	—13	—1.2	—1.2	—1.1	—11	—10	—13	+1.4	+1.5	+1.4
7 30	+35	+31	+23	—1.4	—1.3	—0.7	+28	+24	+11	+1.6	+1.4	+0.8
8 30	+39	+35	+33	—0.7	—0.7	—0.5	+61	+51	+41	+0.9	+0.3	—0.1
9 30	+49	+40	+33	—0.1	—0.2	—0.1	+46	+33	+11	—0.1	0.0	+0.2
10 30	+37	+33	+23	+0.6	+0.3	+0.1	+33	+32	+27	—0.3	—0.2	—0.2
11 30	+15	+19	+29	+0.8	+0.7	+0.6	+11	+22	+40	—1.1	—0.9	—0.7
Range,	87	84	76	2.7	2.5	2.1	90	84	76	2.7	2.6	2.3

The ranges of the inequality for time and height were taken from a graphical process to free them from the incidental irregularities of the tabular numbers.

As the parallax *increases* the range of the inequality in time for high and for low water *decreases* at the rate of nearly 3^m for high water, and of nearly 4^m for low water, for each minute of change of parallax.

With respect to the inequality range in height an *increase* of parallax is followed by a *decrease* in the range for high and low water; this latter result, however, I do not think as fully established.

The parallactic results for Liverpool and London (Phil. Trans. 1836) accord, upon the whole, quite well with those given above for Port Foulke; only results for high water[1] are given.

The variations in the *retard* of the tide depending on variations of parallax were made out by means of a graphical process; it appears that for *increasing* parallax the angle α *increases* for high and low water at a rate of about 3^m for each minute of parallactic change. This accords also well with the Liverpool result.

Effect of Changes of the Moon's Declination on the Half-monthly Inequality.—The effect of the declination changes may be found by the use of the same method as that employed in the parallactic investigation, but as the declination effect varies as the *square* of the declination, the greater the number of groups, arranged for declinations between 0° and ±26°, the more reliable will be the result. Our short series will not permit the formation of even two full groups, the first comprising declinations between 0° and ±16°, the second between ±16° and ±26°. The moon's declination *preceding* the effect by one day has been employed. It was found necessary to contract the tabulation of the half-monthly inequality from 12 to 6 values; for transits near 1^h and 11^h only high declinations occur; for transits near 7^h only low ones; no results could therefore be inserted for these hours. D stands for declination.

[1] Far less attention has hitherto been given to the laws of low water than to those of high water; the latter are *practically* of greater importance, but *theoretically* there is no difference in their value.

Lunar-declination effect on the Half-monthly Inequality.												
☾'s tra.	High water. Inequality in time.			Low water. Inequality in time.			High water. Inequality in height.			Low water. Inequality in height.		
	D=±8°	±16°	±23°	D=±8°	±16°	±23°	D=±8°	±16°	±23°	D=±8°	±16°	±23°
1^h	- - - -	11^h08^m	- - - -	- - - -	17^h13^m	- - - -	- - -	$21^{ft}.5$	- - -	- - -	$11^{ft}.8$	- - -
3	10^h41^m	10 37	10^h36^m	16^h49^m	16 48	16^h47^m	$21^{ft}.4$	21.4	$21^{ft}.3$	$12^{ft}.2$	12.3	$12^{ft}.2$
5	10 40	10 39	10 33	16 46	16 42	16 44	20.0	20.0	20.2	13.4	13.4	13.5
7	- - - -	11 27	- - - -	- - - -	17 27	- - - -	- - -	19.3	- - -	- - -	14.2	- - -
9	11 46	11 52	(11 57)?	18 18	18 01	17 52	20.0	20.1	20.2	12.7	13.0	13.2
11	- - - -	11 40	- - - -	- - - -	17 46	- - - -	- - -	21.0	- - -	- - -	12.2	- - -
Mean,		11 14			17 19½			20.6			12.8	

From the above compilation we can infer that for *increasing* declination the *non-periodical* part of the half-monthly inequality *decreases;* this applies to the times of high and of low water; the total range between 0° and ±26° probably amounts to a few minutes. Respecting the heights, an *increase* of the moon's declination probably produces a *decrease* (in the non-periodic part) of the height of high water, and certainly an *increase* in the height of low water; the range, therefore, will diminish with an increase of declination. The total range between zero and maximum declination probably amounts to a fraction of a foot.

The periodical and epochal part of the declination effect cannot be investigated on account of an insufficiency of material; for the same reason we are compelled to omit any discussion of the effect of changes of the solar declination and parallax, which would demand a series of observations extending at least over one year.

Investigation of the Diurnal Inequality.—The phenomenon of *alternate* higher and lower high waters and *alternate* higher and lower low waters, also *alternate* earlier and later high or low waters, is known as that of the diurnal inequality. Its cycle is a lunar day, and as its magnitude depends on the moon's declination, it goes through its phases in about 14 days, or half a lunation. Generally speaking, and without reference to retard, this inequality vanishes when the moon passes the equator, and reaches its greatest development when the moon attains its greatest north or south declination. The full effect is not generally reached until several days after the moon has passed these positions. The high waters alone may be principally affected, or the low waters alone, or both may exhibit the inequality. Part also of this diurnal tide depends on the sun, and appears therefore in certain months of the year more distinct, and in other months less so. The tidal theories agree in assigning a large diurnal inequality to the middle latitudes, and a small one to equatorial and polar latitudes, the existence of the diurnal inequality in Baffin Bay, along the west coast of Greenland, has long been known to navigators, and by the labors of Dr. Kane it has been traced beyond Smith Strait as far up as latitude 78½° N. The present series not only confirms these results but gives us by far the better special knowledge of the various features of the phenomenon. The diurnal inequality experienced in these high latitudes is evidently the result of the propa-

gation of the diurnal wave through the Atlantic Ocean and up Baffin Bay. We shall now enter more fully into the phenomena, and commence with the

Diurnal Inequality in Height.—On Plate I the observed tides of the winter and summer series have been laid down graphically in time and height; this was done directly from the numbers of Table II. The few wanting tides were interpolated, and are shown by dots. The high waters, depending on the moon's *upper* transit, as well as the low waters *following*, which depend on the same transit, are distinguished from those high and low waters which follow the moon's *lower* transit, by a simple dot at their extremity; whereas the latter have a small circle attached. To render the diurnal inequality more conspicuous, the dots of the high and of the low waters were each connected by a full line, and the circles by lines of dashes.

The vertical distances between this full line and the line of dashes are re-plotted on a straight axis (of abscissæ) and exhibited below each series of observations, the first for high, the second for low water. On the same axis zero declination (of the moon) is indicated by a small circle, and greatest north or south declination by a small bar. The diurnal inequality in height is greater for the high waters and less for the low waters, and that *high* water which follows the moon's *upper* transit (about 11 hours) when she has *north* declination is the higher of the two of that day;[1] when, on the contrary, she has *south* declination, it will be the lower of the two. The same rule was found from the Rensselaer Harbor tides. For the low waters the rule cannot conveniently be stated in this form owing to a remarkable circumstance, namely, the *simultaneous* occurrence of *no* inequality in the *high* waters with *greatest* inequality in the *low* waters, and consequently also the occurrence of the greatest high water inequality with no inequality in the low waters; this is very plainly shown in the diagrams on Plate I. This singular feature has heretofore, as far as known to me, not been found for any station on the Atlantic, or depending on this ocean for its tides; but it was detected in Puget Sound on the Pacific, which the reader will find noticed in the reports of the Superintendent of the U. S. Coast Survey for the year 1859 (p. 144), and in three subsequent reports. The rule, however, which applies there to the height of high water applies at Port Foulke to the low water, and vice versa.

The apparent retard of the high water epoch is as follows:—

☾'s declination zero.	Inequality vanishes.	Interval.
1860. Nov. 22^d, 0^h A. M.	23^d 0^h P. M.	1^d 12^h
Dec. 5, 11 P. M.	7 6 P. M.	1 19
" 19, 7 A. M.	21 6 P. M.	2 11
1861. June 15, 7 A. M.	16 4 P. M.	1 9
" 28, 7 A. M.	30 6 P. M.	2 11

On the average, therefore, the diurnal inequality in the height of high waters disappears 1.9 day after the moon's passage over the equator; the corresponding quantity at Van Rensselaer Harbor was 1.6 day.

[1] This rule depends also on the particular transit of the moon first fixed upon to connect with the tide, and the desirability of extending the establishment beyond twelve hours; thus the rule for high water, given by the Rev. W. Whewell for our Atlantic coast (6th Series of Tidal Researches, Phil. Trans. 1836) will be found the opposite of that given in our U. S. Coast Survey Reports for the Pacific coast of the United States. Port Foulke follows the rule of the latter.

The apparent retard of the low water epoch is as follows:—

	☾'s declination zero.	Inequality vanishes.	Interval.
1860.	Nov. 22^d, 0^h A. M.	Dec. 1^d 6 P. M.	9^d 18^h
	Dec. 5, 11 P. M.	" 16 0 A. M.	10 1
1861.	June 1, 0 A. M.	June 11 4 A. M.	10 4
	" 15, 7 A. M.	" 24 0 A. M.	8 17
	" 28, 7 A. M.	{ July 7 0 A. M. / " 10 6 P. M. }	10 14

On the average, therefore, the diurnal inequality in the height of low water disappears 9.8 days after the moon's passage over the equator.

This difference in the epoch of the inequality in the height of high and low water, amounting to 7.9 days, is significant. With respect to the retard we remark, generally, for tidal waves that their oscillations are augmented by the continued action, in the same direction, of the force having the same intervals as those oscillations; they will, therefore, go on increasing for a considerable time after the forces have gone on diminishing; here the retard is due to an accumulated effect. It is plain that this explanation cannot apply to the epoch of the diurnal wave which shows an epochal difference of nearly eight days for high and low water, but must be the effect of *interference* of the diurnal and semi-diurnal wave. The subject of separation of these two waves will be taken up and analyzed further on.

By means of the diagrams on Plate I we find the maximum range of the diurnal inequality in height for high water to be 3.8 feet, determined from five cases, each giving the same amount. For the low water diurnal inequality range the values are more variable; they are 2.0, 3.7, 2.3, 2.2, and 2.0 feet, on the average 2.4 feet. The last three values belong to the summer series, and are probably affected by the solar action. The variations in the moon's parallax also affect the diurnal inequality, and there are indications of an increase for a larger parallax; our series, however, are too short to pursue this subject any further.

According to Sir J. Lubbock (Phil. Trans. 1837) the lunar portion of the diurnal inequality can be represented by

$$dh = C \sin 2\delta' \text{ for the heights, and } d\psi = \frac{G \tan \delta'}{1 + A \cos 2\phi} \text{ for the times.}$$

In these expressions the value of δ' must be taken for an anterior date, which for the high water height inequality in our case is two days. Dividing the intervals between the moon's zero declination in six equal parts, and measuring for each the ordinate of the inequality and tabulating the corresponding declinations, without regard to sign, we obtain the following results for the inequality in height of high water from the two series. Each value is the result of five separate measures, and the computed value is derived from the expression $dh = 4.6 \sin 2\delta'$.

δ'	Observed dh	Computed dh
0°	0^{ft}.0	0^{ft}.0
12	1.8	1.9
22	3.2	3.2
25	3.5	3.5
22	3.1	3.2
12	1.8	1.9
0	0.0	0.0

The inequality in the heights of low water cannot be expressed in this manner, as the more complex figure on Plate I sufficiently indicates.

That low water which follows the moon's upper transit (about 17 hours) when she has north declination is the lower of the two, provided it happens ten days after the zero declination; if before, it is the higher of that day. A similar restriction, of two days only, applies to the rule for the highest high water.

Diurnal Inequality in Time.—The inequality in time is best exhibited by means of diagrams, the abscissæ of which are the times of high or low water, and the ordinates the corresponding lunitidal intervals, both taken from Table II. Lunitidal intervals from the upper transits are indicated by dots; intervals from the lower transits by small circles. The observations of the winter series proved somewhat too rough for the elucidation of this inequality—they were taken every half hour; the diurnal inequality, nevertheless, is sufficiently indicated to make out its general law. I shall here confine this investigation to the second series, for which we have observations every ten minutes; the results are given on Plate II for high water and low water separately. The inequality, proper, is shown underneath, where the middle line between the full and broken curves of inequality is straightened out and forms the axis of abscissæ, upon which the time inequalities, as ordinates, have been plotted. From these curves we find the retard of the time inequality for high water from three intersections with the axis equal 11.0 days, and that of low water equal 2.2 days. A comparison of these time-curves of Plate II with the height-curves of Plate I, indicates a strong similarity in character between the *height* inequality of *high* water and the *time* inequality of *low* water; for these curves the average epoch is two days, and the alternation each semi-lunation of the signs or full curves *above* and *below* the axis correspond; a similar correspondence of epoch, which is on the average 10.4 days, and of alternation of the signs exists in the time inequality of high water and the height inequality of low water. This is not an accidental relation, but has been recognized at other stations, the first and conspicuous notice of it I find in the U. S. Coast Survey Report for 1853, p. *79 in the tidal discussion by A. D. Bache, Superintendent, of Rincon Point, San Francisco, California.

The greatest range of the time inequality is for the high waters 46^m, and for the low waters 58^m, the first from two, the last from three determinations.

Respecting the relative magnitude of the inequality we have, on the one hand, the *smaller* time and *greater* height inequality in high water, and on the other, the *greater* time and *smaller* height inequality in low water.

A similar relation of magnitudes occurs at Rincon Point, but it is the reverse of that just stated, in conformity with the more prominent development of the diurnal inequality in the height of low waters in San Francisco Bay.

The interval of that high water which follows the moon's upper transit (about 11 hours) when she has north declination will be the smaller one, provided it happens 11 days after the moon's zero declination; if before, it will be the greater of the two of that day. The interval of that low water which follows the moon's upper transit (about 17 hours) when she has north declination will be the greater of the two provided it happens two days after the moon's zero declination; if before, it will be the earlier one. The reverse takes place for south declination, or for lower transit.

The time-inequality of the low water of the second series can be represented well

enough by the approximate formula $d\psi = 102 \tan \delta'$, the declination of the moon being taken for an anterior epoch of two days.

δ'	Observed $d\psi$	Computed $d\psi$
0°	0^m	0^m
13	42	25
22	41	41
25	48	48
21	27	40
12	24	22
0	0	0

The curve thus computed is represented on Plate II; see bottom diagram. Corresponding to this curve the bottom diagram of Plate I shows the computed height inequality for high water.

Separation of the Diurnal and Semi-Diurnal Waves.—The compound wave actually observed consists of the diurnal wave, to which the diurnal inequality is due, and of the ordinary semi-diurnal wave which produces the ordinary tides. For a complete study of these waves it is necessary to have them in their separate forms. The manner in which this separation will be effected is the same as that employed in the U. S. Coast Survey; it was originally proposed by Assistant L. F. Pourtales, in charge of the tidal party, about the year 1855,[1] and has taken the place of the more laborious analytical process previously employed; the graphical process of Mr. Whewell's was applied only to observed high and low waters, and consequently gave but few points of the diurnal wave.[2] In Series II the high and low waters alone were observed, which renders it quite unsuitable for the purpose of separation. I was therefore obliged to select the least interrupted portion of the half-hourly observations of Series I. The compound (observed) wave, and its two component waves from November 21 to December 11, 1860, are shown on Plate III. The graphical process of separation is as follows: After the observations are plotted and a tracing is taken, the traced curves are shifted in epoch 12 hours 24 minutes *forward*, when a mean curve is pricked off exactly *between* the observed and traced curves; the same process is repeated after the paper was shifted 12 hours 24 minutes *backwards*, when a second pricked curve is obtained; the mean pricked curve then represents the semi-diurnal wave. To obtain the diurnal curve we have only to lay off the differences between the observed curve and the semi-diurnal curve. The process is simplified by blacking the under surface of the tracing paper with a lead pencil and running in with a free hand the intermediate curve by the pressure of a steel point which leaves a sufficient mark on the paper; the average of the two curves thus traced gives the semi-diurnal wave in quite an expeditious manner. Nevertheless the discussion, by separate waves, of any lengthy series of observations remains a laborious task. On Plate III the observed heights, reduced to the same plane of reference or zero level, are shown by dots, and connected by a full line; some omissions in the observations are supplied by dots; the average level reads 16.7 feet. The semi-diurnal wave is shown by a curve of dashes, and the diurnal

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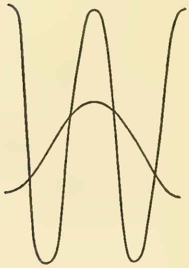
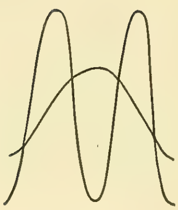
[1] See my discussion of the Van Rensselaer Harbor tides, p. 78, where the method is first published, by permission of A. D. Bache, Superintendent U. S. Coast Survey.

[2] See 8th Series of Researches of Tides. Phil. Trans. 1837.

wave by a full line constructed over the average level as an axis of abscissæ. The combination of the two component waves will show the features of the diurnal inequality; thus, the upper of the two annexed diagrams exhibits the position of the semi-diurnal wave on November 30, when the inequality in the height of high water is *greatest*, and when the low waters show *no* inequality since they are affected alike. On the contrary, the lower figure exhibts the position on December 8, when there is *no* inequality in the high waters, and the greatest inequality in the height of low water. In the upper case the maximum ordinates or the high waters of the two waves coincide; in the lower case they are opposed, or the high water of the diurnal wave coincides with the low water of the semi-diurnal. As the semi-diurnal wave progresses or gains on the diurnal all possible variations are gone through successively. For the upper diagram the *time* of the first low water will be earlier or its luni-tidal interval shorter, and the time of the second low water will be later, or its luni-tidal interval will be greater; the time of the intermediate high water will not be affected. For the lower diagram the time of the first high water will be later, and that of the second earlier; the interval of occurrence between these high waters will therefore be considerably shortened. The time of the intermediate low water will not be affected.





The average range of the diurnal tide for the period represented on Plate III is about three feet, and for the semi-diurnal about seven feet, the greatest and least ranges for these waves are four feet and two feet nearly for the first, and ten feet and four feet nearly for the last. The diurnal wave gradually increases in size from the time of the moon's zero declination to the time of its maximum declination, as shown on the Plate.

The epoch of the diurnal wave appears to remain sensibly the same during the twenty days for which it has been brought out; that is to say, its high water appears to occur at noon, and consequently its low water at midnight; the variations from these hours are confined within an hour before or after. The Van Rensselaer Harbor tides afforded but a bare glimpse at the diurnal tide which occurred between October 30 and November 22, 1853, there also its high water appeared to hang about the hours two or three after noon, and its low water the same number of hours after midnight; but as theory points out a different relation than that of solar time, *and consequently a gradual slow shifting from the solar hours*, and as our series is too short to show its conformity or non-conformity therewith, we are compelled to leave this interesting branch of the discussion.

Owing to the variation in the epoch of the diurnal wave, its rate of progress from Port Foulke to Van Rensselaer Harbor cannot be made out directly, since the observations were not contemporaneous, although future observations at some

southern point of Baffin Bay would probably enable us to trace its course northwards through this channel

Investigation of the Form of the Tide Waves.—The compound character of the wave requires a separate investigation of the forms of the diurnal and of the semi-diurnal wave. We have seen that the diurnal wave undergoes smaller fluctuations of range than the semi-diurnal, in which latter the spring and neap tides are fully developed. To obtain the average slope of these waves the time between two successive low waters was divided in six equal parts, for each of these phases the ordinates were measured from the low water level. The ordinates of 20 diurnal waves and of 38 corresponding semi-diurnal waves, were thus ascertained and their mean values taken. Applying to these measures Bessel's circular function[1] the average forms of these waves, from twenty days of observation, are given by the following expressions:—

For the diurnal wave

$$1^{ft}.50 + 1.56 \sin(\theta + 270°) + 0.08 \sin(2\theta + 135°)$$

For the semi-diurnal wave

$$3.75 + 3.79 \sin(\theta + 275°) + 0.21 \sin(2\theta + 194°)$$

The observed and computed values agree as follows:—

Diurnal wave.			Semi-diurnal wave.		
Observed.	Computed.	Difference.	Observed.	Computed.	Difference.
$0^{ft}.0$	$0^{ft}.0$	$0^{ft}.0$	$0^{ft}.0$	$-0^{ft}.1$	$+0^{ft}.1$
0.6	0.5	+0.1	1.9	+2.2	—0.3
2.3	2.5	—0.2	6.2	+6.1	+0.1
3.1	3.1	0.0	7.4	+7.5	—0.1
2.2	2.4	—0.2	5.3	+5.2	+0.1
0.7	0.6	+0.1	1.7	+1.8	—0.1
0.0	0.0	0.0	0.0	—0.1	+0.1

In the above expressions the angle θ counts from low water (0°) to the following low water (360°), for the first wave it passes through its values in a day nearly, for the second in twelve lunar hours; the ordinates are expressed in feet. The diurnal curve appears to be nearly symmetrical, but the preceding slope of the semi-diurnal wave appears steeper than the following slope; the difference, however, is slight.

The difference in the establishments of high and low water is $6^h\ 05^m.7$, which represents the duration of *fall*, the duration of *rise* consequently is $6^h\ 18^m.7$; the rise occupies therefore more time than the fall; the difference is 13^m. At Van Rensselaer Harbor this difference was 15^m, the water also rising longer.[2] This appears to be the rule for all localities which receive the direct ocean tide wave; the form of the wave, however, changes when ascending a *shallow* bay or a river, and reverses the duration of the tide, making the rise the shorter.

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[1] Development of Bessel's function for the effect of periodic forces, etc , U. S. Coast Survey Report for 1862, Appendix No. 22.

[2] In the discussion of the Van Rensselaer Harbor tides, p. 80, the reverse is inadvertently stated.

Progress of the Tide through Baffin Bay.—In the following table I have collected all the tidal information I could find respecting establishment and range of stations on the west coast of Greenland, for the purpose of showing the northerly propagation of the tide wave through Baffin Bay. This locality is well suited for testing the theoretical deductions, according to the tidal theory of canals, the bay being sufficiently regular and of great length, with the full Atlantic tide thrown into it at its southern end. Its tides will therefore be of a derivative character chiefly, since any forced tide produced in it must be, comparatively very small, and would produce waves of an undulatory character. For this purpose it would be very desirable to obtain some sets of unexceptionable tidal observations[1] on both shores of the bay, each extending over at least two lunations.

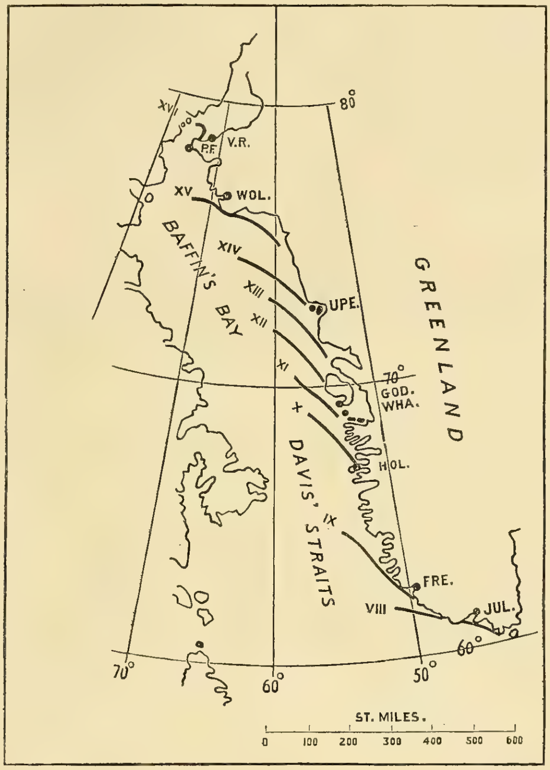
Locality.	Latitude.	Longitude west of Greenwich.	High water lunitidal interval F. and C.	Rise and fall spring tides.	neap tides.	Authority or reference.
Julianshaab,	60° 35′	46° 05′	5h 6m	7ft	5ft	British Admiralty Tide Tables for 1865.
Frederickshaab,	62 00	50 05	6 3	12½	9¼	
Holsteinborg,	66 56	53 42	6 30	10	—	Capt. Inglefield, 1853.
Whalefish Islands,	68 59	53 13	8 15	7½	—	Parry's Third Voyage.
Godhavn,	69 12	53 28	9 00	7½	—	Map, in Narrative of Kane's First Voyage.
Upernavik,	72 47	56 03	11 00	8	—	Capt. Inglefield, 1854.
Wolstenholm Sound,	76 33	68 56	11 08	7½	7(?)	MS. furnished by the late hydrographer to the Admiralty.
Port Foulke,	78 18	73 00	11 24	9.9	5.0	Dr. Hayes' Obser's, 1860–61.
Van Rensselaer Har.	78 37	70 53	11 52	10.8	4.9	Dr. Kane's Obser's, 1853–54.

To trace the cotidal lines or the high water ridges of the tidal wave, as it progresses, it is preferable, for comparison, to use the mean for the above vulgar establishment; 10m were therefore subtracted from the interval at full and change. To correct for the moon's motion in the interval, 1m is subtracted for every half hour of interval; adding the west longitude from Greenwich we obtain the corresponding Greenwich time or the cotidal hour and minute.

Locality.	Mean establishment.	Correction for ☾	Longitude.	Cotidal hour and minute.
Julianshaab	4h 56m	—9m	3h 04m	7h 51m
Frederickshaab.	5 53	—12	3 20	9 01
Holsteinborg	6 20	—13	3 35	9 42
Whalefish Islands, ...	8 05	—16	3 33	11 22
Godhavn	8 50	—18	3 34	12 06
Upernavik	10 50	—22	3 44	14 12
Wolstenholm Sound.	10 58	—22	4 36	15 12
Port Foulke	11 14	—23	4 52	15 43
Van Rensselaer Harbor	11 43	—23	4 44	16 04

[1] Suitable localities would be Cape Farewell, Cape St. Lewis in Labrador, Cape Walsingham, and Ponds Strait. It is to be regretted that no tidal observations were made in Kennedy Channel, as by means of these the question of its open or closed character, to the northward, could be partly answered.

These cotidal lines, which connect all places having high water at the same (Greenwich) time, are laid down on the accompanying chart.[1] The tide wave consumes very nearly eight hours in travelling from the southern cape of Greenland to Smith Sound.



Average Depth of Davis Strait, Baffin Bay, and Smith Strait.—By means of the preceding cotidal hours and the known distances of the localities in connection with the theoretical deductions of Art. (174) "Tides and Waves," we find the average depth of the sea along the channel-way as follows:—

Davis Strait. Distance from Julianshaab to Whalefish Islands 680 statute miles nearly; difference in cotidal hour $3^h.5$, hence velocity in statute miles per hour 194, and corresponding depth 2510 feet or 418 fathoms.

[1] The general cotidal chart constructed by Mr. Whewell, more than thirty years ago (and reproduced in the astronomer royal's essay, "Tides and Waves"), is very defective to the eastward of New Foundland, as will appear in attempting to join our cotidal lines with it; it is due to the total neglect of the powerful retarding influence of the *banks* of New Foundland.

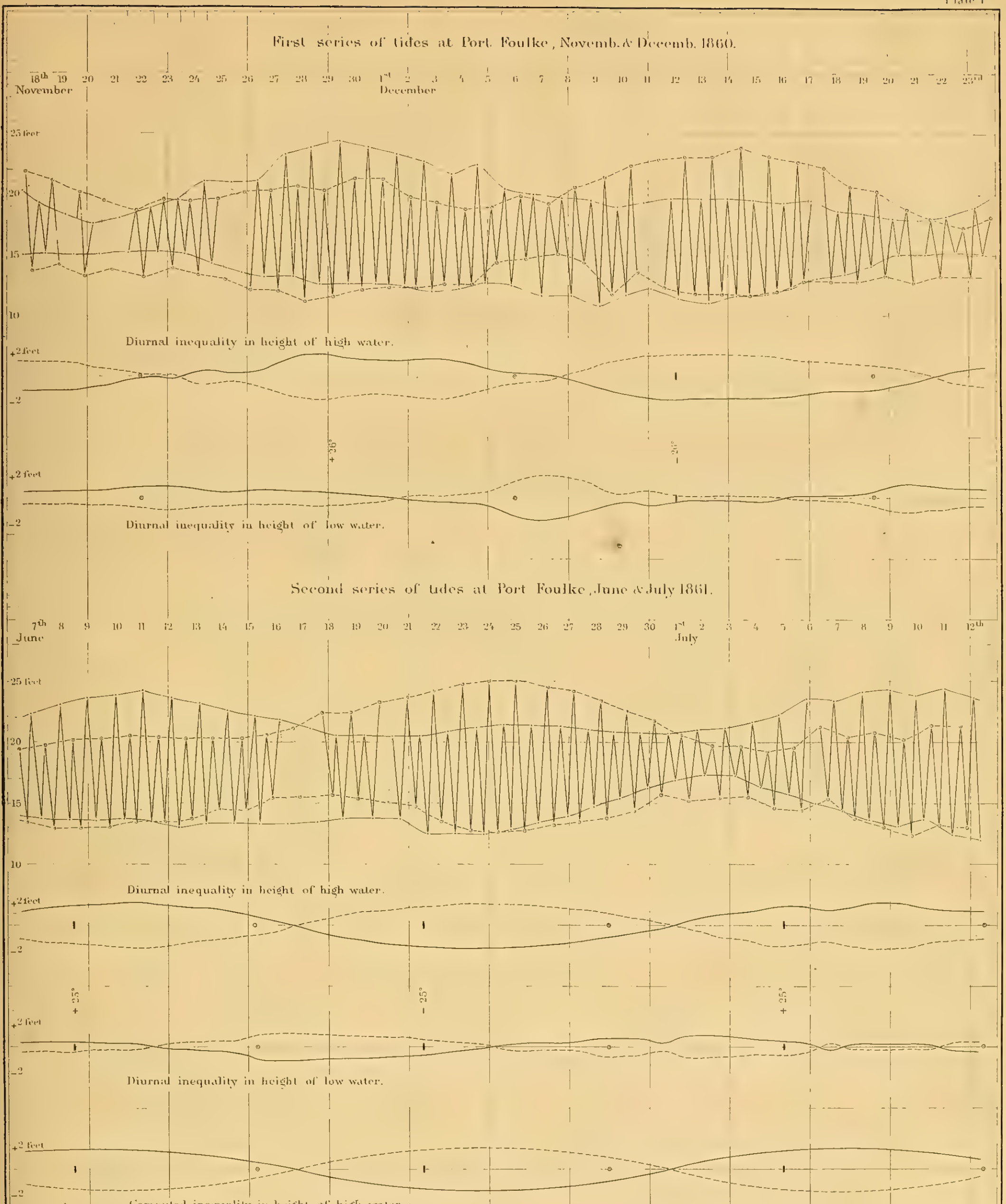
Baffin Bay. Distance from Whalefish Islands to Port Foulke 770 statute miles nearly; difference in cotidal hour $4^h.35$; hence velocity in statute miles per hour 177, and corresponding depth 2095 feet, or 349 fathoms.

Smith Strait. Distance from Port Foulke to Van Rensselaer Harbor 55 statute miles; difference in cotidal hour $0^h.35$; hence velocity in statute miles per hour 157, and corresponding depth 1663 feet, or 277 fathoms.

The average depth, according to the above, of Davis Strait and Baffin Bay is, therefore, about 383 fathoms, the length of the free tide wave nearly 2300 statute miles, with a height between trough and crest of about $7\frac{1}{2}$ feet.

The average depth, as found from the velocity of the tide wave, appears to accord well with the few soundings we possess, and the result I consider entitled to confidence.

Plate I



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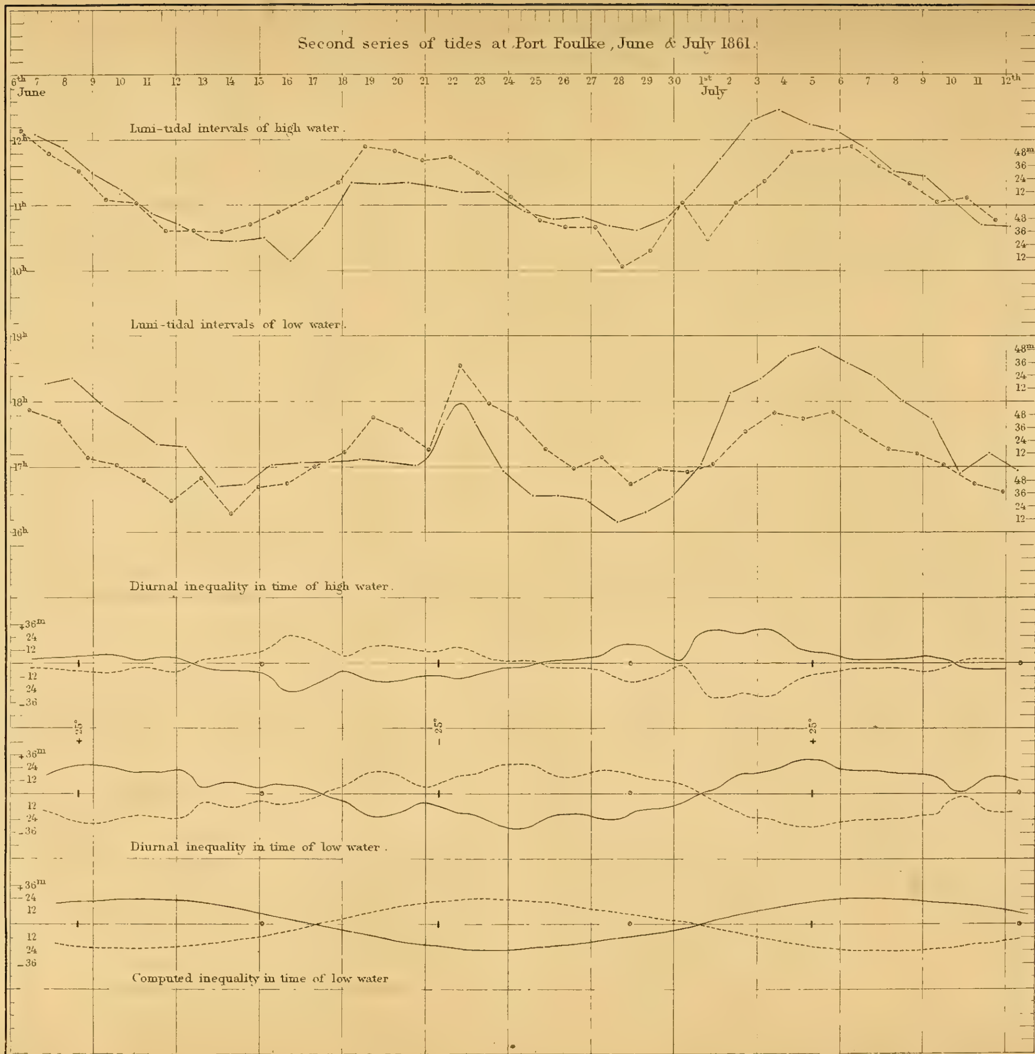
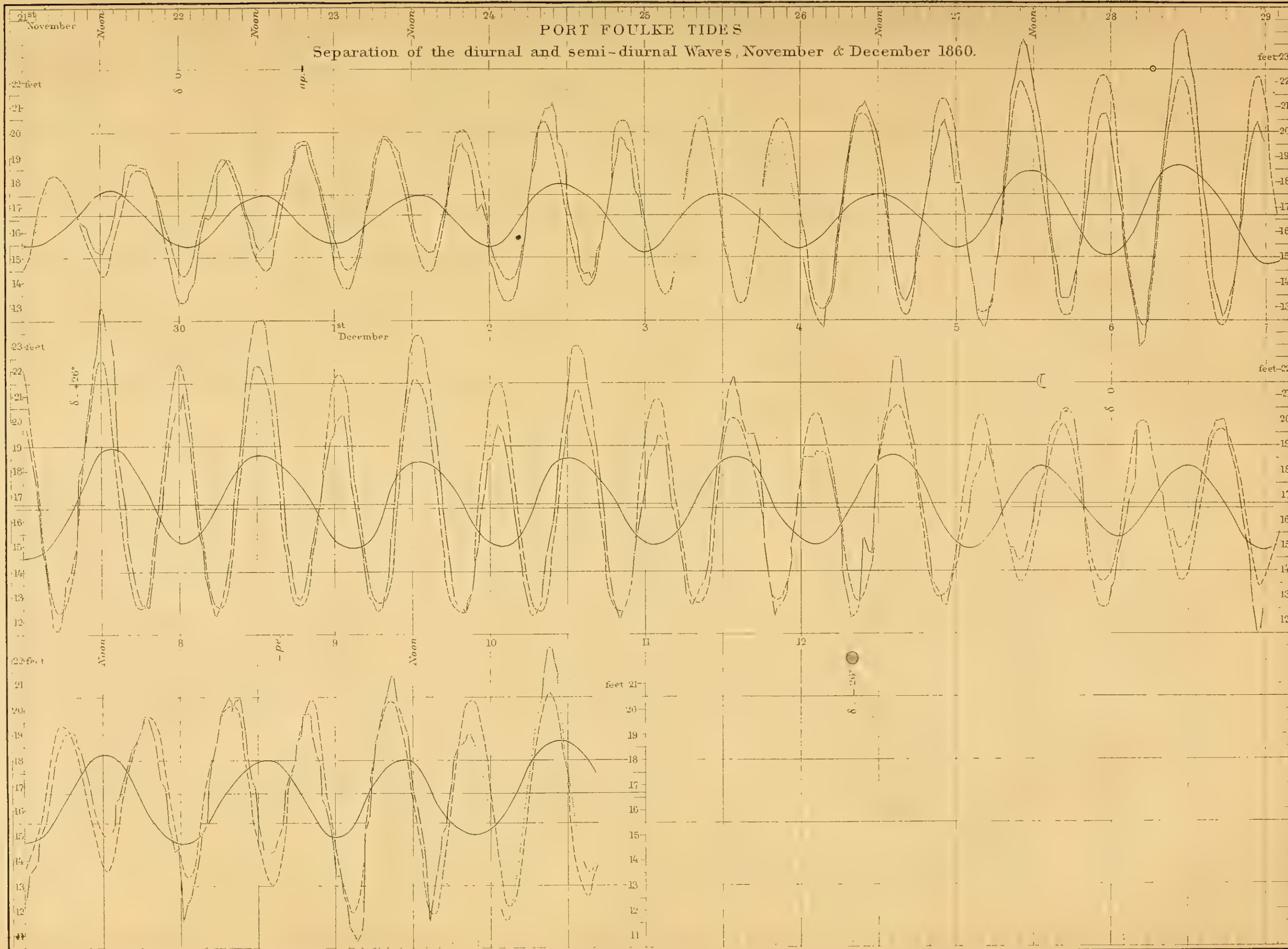

Second series of tides at Port Foulke, June & July 1861.
6th June 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1st July 2 3 4 5 6 7 8 9 10 11 12th
Luni-tidal intervals of high water.
12h
11h
10h
48m 36 24 12
48 36 24 12
Luni-tidal intervals of low water.
19h
18h
17h
16h
Diurnal inequality in time of high water.
+36m 24 12
12 24 -36
+25°
-25°
+25°
Diurnal inequality in time of low water.
Computed inequality in time of low water

PORT FOULKE TIDES

Separation of the diurnal and semi-diurnal Waves, November & December 1860.



A. Peterson sc.

PART IV.

METEOROLOGICAL OBSERVATIONS.

RECORD AND RESULTS

OF

METEOROLOGICAL OBSERVATIONS.

THE fourth and last part of the publication of the records and results of Dr. Hayes' Arctic Expedition of 1860 and 1861, herewith presented, comprises meteorology, and will be given under the subdivisions, temperature, atmospheric pressure, and wind.

By inspecting the general track chart and the special harbor chart of the winter quarters, illustrating Part I, or the astronomical results, it will be seen that Port Foulke, latitude 78° 17′.6 N. and longitude 73° 00′.0 W. of Greenwich, has a free exposure to the westward (true), directly facing Smith Strait and nearly opposite Cape Isabella. The harbor is on the south side of the entrance to a large fiord, at the eastern terminus of which is situated Lake Alida, which receives the drainage of a large glacier named by Dr. Kane "Brother John's glacier." This glacier protrudes into the upper end of the fiord and forms part of an immense mer de glace extending far into the interior, and is connected with the great Humboldt glacier. Dr. Hayes travelled over this glacier, in an easterly direction, for fifty-three miles.

The locality may be said to be, climatologically, an anomalous one, as it is fully under the immediate influence of the upper north water and the smaller water areas of Smith Strait. The sea, here, does not freeze over entirely during the winter, but presents large patches of open water which exercise a powerful influence over the climate of this region. Dr. Hayes remarked that during the winter of 1860—1861, the open sea could always be found a few miles to the westward of his anchorage. The comparative mildness of the climate makes it possible for the Esquimaux to reside habitually during the winter in this high latitude, and the vicinity of the port abounds with animal life which was almost entirely absent at Van Rensselaer Harbor, but a short distance to the northward and eastward. This contrast in the climate cannot be better illustrated than by stating the fact of the temperature simultaneously recorded on March 18, 19, 20, 21, 1861, at Port Foulke and at Van Rensselaer Harbor, then revisited by Dr. Hayes, at the former place it was —24°.7 and the latter —50°.7 as observed by him, showing a difference of not less than 26° of greater cold at Van Rensselaer Harbor.

On August 26th, 1860, Capes Alexander and Isabella were first sighted; on September 9th, at 5 P. M., the vessel was safely moored for the winter at Port Foulke,

Smith Strait; the interval between these dates was consumed in the attempt of beating in and through the strait. During this interval the climatic relations were so nearly the same as those at Port Foulke that we may conveniently commence the meteorological record with September 1, 1860. The observations extend to July 14th (10 A. M.), 1861, at which date the vessel was unmoored and pulled out of the harbor; crossing the strait, the schooner anchored for several days in the vicinity of Cape Isabella; on the 29th she was off Gale Point; and on the 31st some short distance to the southward of Cadogan Inlet. We may, therefore, combine, without much risk of error, the recorded observations during the latter half of July with the preceding record, and thus form a continuous meteorological record for Port Foulke, extending over eleven months. A proper method of interpolation will enable us to deduce a mean value for each meteorological element for the twelfth month, and the annual mean values may safely be made out.

The results will be further illustrated by comparison with those obtained from Dr. Kane's[1] and Sir F. L. McClintock's[2] expeditions, as published by the Smithsonian Institution in 1859 and 1862.

Taking the refraction into consideration, the sun's upper limb would, in the latitude of Port Foulke, astronomically disappear after October 25th noon, and reappear at noon February 15, thus remaining below the horizon for 113 days, or nearly three and two-third months. Owing to the surrounding cliffs the sun did not make its appearance at the harbor until February 18.

TEMPERATURE.

The expedition was supplied with about two dozen thermometers of different kinds, graduated according to Fahrenheit's scale, excepting two, which were divided in degrees of Reaumur. Some were spirit, others mercurial thermometers; there was also one metallic thermometer. Three of the instruments were considered of standard excellence, and of these No. 3 was selected by Mr. Sonntag as the standard, to which accordingly the indications of all others will be referred.

Thermometers Nos. 1, 2, 3, are standard instruments. No. 3 was selected as the most reliable. (They are, no doubt, spirit thermometers.)

Nos. 4, 5, 6, ordinary thermometers (supposed spirit thermometers).

Nos. 7, 9, mercurial thermometers.

Nos. 8, 10, 12, 13, ordinary thermometers.

M, a metallic thermometer by Beaumont, of New York.

1705, 1657, maximum thermometers; they are mercurial.

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[1] Meteorological Observations in the Arctic Seas, by Elisha Kent Kane, M. D., U. S. N., made during the second Grinnell Expedition in search of Sir John Franklin, in 1853, 1854, and 1855, at Van Rensselaer Harbor and other points on the west coast of Greenland. Reduced and discussed by Charles A. Schott. Smithsonian Contributions to Knowledge, 1859.

[2] Meteorological Observations in the Arctic Seas, by Sir Francis Leopold McClintock, R. N., made on board the Arctic searching yacht "Fox" in Baffin Bay and Prince Regent's Inlet, in 1857, 1858, and 1859. Reduced and discussed, at the expense of the Smithsonian Institution, by Charles A. Schott. Smithsonian Contributions to Knowledge, 1862.

1597, 1639, minimum thermometers; no doubt spirit thermometers.

1663, 1704, both mercurial thermometers; the latter a black bulb.

A, B, two Reaumur thermometers.

1644, 1648, hygrometric and black bulb thermometers.

To allow for errors of graduation the following comparisons were made:—

1. Comparisons of thermometers at the temperature of freezing water, Port Foulke, Smith Strait, September 12, 1860. The thermometers were immersed in a bucketful of melting ice. A. Sonntag, observer. The readings are taken at intervals of five minutes.

	Number or designation of thermometers.															
	3	1	2	4	5	6	7	9	1597	1639	1657	1663	1704	1705	A	B
	32°.0	31°.7	32°.0	31°.5	31°.7	31°.4	31°.0	31°.2	31°.4	32°.3	31°.2	31°.5	32°.0	32°.0	—0°.3	0°.0
	32.0	31.6	31.9	32.0	31.3	31.3	30.8	31.0	31.5	32.2	31.2	31.4	32.0	32.0	—0.4	—0.2
	32.0	31.5	31.8	31.8	31.5	31.3	31.0	31.0	32.0	31.7	31.5	32.0	31.5	32.0	—0.3	0.0
	32.0	31.6	31.8	32.0	31.5	31.3	31.0	31.0		32.2	31.3	31.7		32.0	—0.3	0.0
Mean,	32.0	31.6	31.9	31.8	31.5	31.3	31.0	31.0	31.6	32.1	31.3	31.7	31.8	32.0	—0.3	0.0
Corr'n,	0.0	+0.4	+0.1	+0.2	+0.5	+0.7	+1.0	+1.0	+0.4	—0.1	+0.7	+0.3	+0.2	0.0	+0.3	0.0

2. Comparisons at low temperatures, Port Foulke. The thermometers were suspended on the east side of the Port Foulke meteorological observatory, facing northeast, and were read at intervals of five minutes. March 24, 1861.

	Number or designation of thermometers.						
	3	1	2	4	9	10	M
	—37°.2	—42°.8	- - - - -	—32°.5	—32°.0	- - - - -	—35°.5
	37	42.5	- - - - -	32.2	31.8	- - - - -	35.5
	36.8	42.2	- - - - -	33	31.8	- - - - -	35
	36.8	42.2	—33°.8	33.2	31.8	—39°	35.5
	36.8	42	34.5	33.5	31.8	40	35
	37	42.2	35	33.5	32.0	41.5	35.5
	37	42.5	35.5	33.8	32.0	42	36
Mean,	—37.0	—42.3	—34.7	—33.1	—31.9	—40.6	—35.4
Correction,	0.0	+ 5.3	— 2.3	— 3.9	- - - - -	+ 3.6	— 1.6

The small correction of the metallic thermometer at this extremely low temperature is a satisfactory proof that the low temperatures are correctly ascertained.

3. Other intermediate comparisons by A. Sonntag.

1860.	3	1	4	9	A	1663
October 6th A. M.	21°.3	20°.9	21°.2	21°.9	—4°.8	
" 6th P. M.	23.0	22.3	22.8	23.2	—4.3	
" 9th P. M.	22.6	22.1	22.4	23.0	—4.3	
Mean	22.3	21.8	22.1	22.7	—4.5	
Correction . . .	0.0	+0.5	+0.2	—0.4	+0.1	
October 10th noon,	11.6	10.5	11.3	12.3	— 9	
" 11th A. M.	6.0	4.7	6.0	7.0	—11.4	
" 11th P. M.	12.0	10.8	11.8	12.8	— 8.8	
" 11th P. M.	12.4	11.2	12.1	13.1	— 8.7	
" 12th A. M.	8.7	7.7	8.9	9.7	—10.4	
Mean	10.1	9.0	10.0	11.0	— 9.7	
Correction . . .	0.0	+1.1	+0.1	—0.9	0.0	
- - - - - - -	—10.1	—12.5	—8.8	—7.7	—18.1	—7.8
Correction . . .	0.0	+2.4	—1.3	—2.4	— 0.6	—2.3

4. Additional comparisons of thermometers Nos. 4 and 6 with the standard; these comparisons being very numerous, the results only are given here.

Date.	Temperature by No. 4.	Correction to No. 4.	Number of observations.
1860. November 29	21°	+0°.0	1
" 26	between 12° and 13°	+0.5	2
1860. December 18—March 28 . .	" 2 and —10	—1.4	19
1861. February 4—April 3 . .	" —12 and —19	—2.5	15
" January 21—April 2 . .	" —21 and —28	—3.2	20
" January 23—March 26 . .	" —30 and —38	—3.4	6

Date.	Temperature by No. 6.	Correction to No. 6.	Number of observations.
1860 September 12	31°.3	+0°.7	4
" November 27—November 29 .	between 11° and 14°	+10.7	6
" November 25—November 30 .	" 10 and 0	+10.4	13
" November 12—November 26 .	" — 2 and —10	+11.3	19
" November 13—November 26 .	" —10 and —20	+11.4	20
" November 19—November 21 .	" —20 and —29	+11.6	7

The following corrections were adopted for No. 4:—

Temperature by No. 4.	Correction.
+32°	+0°.2
+22	+0.2
+11	+0.2
— 5	—1.4
—16	—2.5
—25	—3.2
—33	—3.4

A number of simultaneous readings of thermometers Nos. 3, 1, 9, A, 1663, also of a few others, were taken daily between November 12, 1860, and July 12, 1861, at the hours 8 A. M., 2 and 10 P. M. Of these readings such use will be made as circumstances seem to require. There are occasionally omissions in this record. Between November 26, 1860, and March 4, 1861, hourly readings of the same thermometers were taken on fifteen days (at intervals of one week).

Comparison of thermometers No. 3 and No. 13.

These thermometers were read together frequently between April 7, 1861, and July 6, 1861; the following corrections to No. 13 were deduced from these comparisons:—

Temperature by No. 13.	Correction.	Number of observations.
—22°	+1°.4	7
—10	—0.9	17
+ 1	—0.2	25
+17	+1.6	25
+25	+1.8	54
+35	+1.2	74
+45	—1.2	27
+53	—1.9	3

These comparisons being made in the air, are yet sufficiently numerous to give a reliable correction.

Most of the meteorological instruments were kept in a large box on shore near the astronomical and magnetic observatory, in the rear of the harbor.

The record of the temperature of the air comprises daily bi-hourly observations (with occasional omissions) between September 1, 1860, and July 31, 1861. Thermometer No. 7 was used between September 1 and November 7, on which date No. 6 was hung up, No. 7 having been carried away. November 12th, thermometer No. 6 was taken to the meteorological box on shore, and No. 4 substituted, hung on a pole erected on the floe ice near the schooner. On April 5th, No. 13 was substituted for No. 4. On March 16th, the thermometers were changed in position at the box on shore, and on May 23d they were returned on board.

Temperature of the air, in shade, observed near and at Port Foulke, Smith Strait, September, 1860.

Day of the month.	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	Mean of 12 values by No. 7
1	- - -	19°.5	20°	21°	22°	22°	22°	22°.5	24°.5	26°	25°	- - -	22°.4
2	- - -	- - -	- - -	22	22.5	20	20	- - -	- - -	- - -	- - -	- - -	21.1
3	- - -	- - -	- - -	23	23	24	24	24	24	22	22	- - -	22.9
4	- - -	- - -	- - -	24.5	24	21.5	18	17	16.5	16.5	17	17°	20.2
5	- - -	- - -	- - -	21	21.5	22.5	- - -	- - -	- - -	29	29	- - -	23.8
6	- - -	- - -	- - -	29	30	29	28	26	28	26	25	24.5	27.7
7	27°	- - -	- - -	27	27	26	24	23	23	22.5	22.5	- - -	24.9
8	- - -	- - -	- - -	23	24	24	24	24	24.5	24	22	- - -	23.4
9	- - -	- - -	- - -	28	28	27	26	25.5	23	22.5	21.5	21	24.9
10	- - -	- - -	- - -	24	24	26	28	26	25	28	28.5	- - -	25.4
11	- - -	- - -	- - -	27.5	29	31	31	31	30	30.5	32	29	29.5
12	33.5	30	- - -	26	24.5	24	24	24.4	24.2	24	24.5	23	25.8
13	24	25	25	25	24.8	27	26	25	24.2	24	23	22	24.6
14	20	22	22	- - -	20	24	24	- - -	24.8	25.5	26	22.7	23.0
15	23	22.5	20	20	22	- - -	27	27.5	27.3	26.7	26.5	26	24.4
16	30	28.5	30	32	32	- - -	31	31	30.5	27.5	26	24.8	29.6
17	25	25	23	23	22.3	- - -	23.5	23.5	22	- - -	21	18.8	23.6
18	17.5	18	19	21	21	22.5	23	22.5	21	20.5	19	17.5	20.2
19	14.5	15.5	17	18.5	19	21	21.5	20.5	15.7	15.8	15	15	17.4
20	14.5	17	17.5	18	19.5	20	21	20.5	18.2	19.5	19.5	19.5	18.7
21	19	20	- - -	23.5	21.5	20.5	22	23.5	25.7	- - -	- - -	24.5	22.7
22	26	27	- - -	26.3	26	27	30	30	24	21.3	21	19.3	25.4
23	16.5	15.5	- - -	15.3	14.5	- - -	17	19	16.5	16	17	17	16.3
24	17	16	- - -	17	17.7	19.5	21	20.5	21.5	21	21	- - -	19.0
25	17.6	19	21	20	- - -	- - -	20	20.5	- - -	18	18.5	16.5	19.2
26	- - -	19	19.5	17	16	18	18.3	17	- - -	16	15.5	14	17.0
27	- - -	- - -	14	15	- - -	- - -	- - -	19.5	19.5	- - -	- - -	21.5	17.5
28	23	22.5	22.5	22	- - -	- - -	17	- - -	16.8	17	13	10.3	18.4
29	7.5	9	8.5	7.3	10	9	10	9	8	8.5	9	8.5	8.7
30	- - -	10	9.5	10	9.5	10	10.5	11	11	11.8	11	11.3	10.4

Thermometer No. 7 hung on a pole on the floe ice near the vessel. This thermometer is used till Nov. 7th.

October, 1860.

Day of the month.	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	Mean of 12 values by No. 7.
1	14°.5	- - -	14°.5	14°.5	14°.5	13°.5	13°.5	14°	16°	16°	16°.2	20°	+15°.1
2	17	19.5	24	23.8	24.5	24.5	22.5	23	20	17	- - -	13.6	+20.4
3	- - -	13	14.5	15	- - -	- - -	25	26	25	25	23.5	24.5	+20.4
4	25	- - -	24.5	23.5	24.5	24.5	24.5	25	24.5	25	24	24.5	+24.5
5	23.5	24	- - -	25	24.5	24.5	24	20.5	20	18.5	17.5	17.8	+22.0
6	17	16.5	19	20	20.5	22	23.5	23	23	23	23	24	+21.2
7	24	- - -	14.5	23.2	23.5	24	25	25	25.3	25.5	27	- - -	+23.7
8	- - -	26	27	27	27	27.5	28	28	27.5	27.5	27	26.5	+27.1
9	27.5	26.5	- - -	27.5	26.5	27.5	27	26	25	23	19	20	+25.2
10	21	16	- - -	16	15	11.6	14.5	14.5	15	15	12	13.5	+15.0
11	10.5	10	- - -	6	11.5	12	12.4	17	11	12	10	11	+10.9
12	7	7	9	9	8.7	13	10.5	14	15	15.5	15	10	+11.1
13	10.5	9.5	10	8.5	9.3	8.8	- - -	4	3.5	—0.5	—1	—3	+5.5
14	—2	—3	—2	—0.5	—1	—1	—2	—1.5	—2	—2	—4	—8	—2.4
15	—7	—6	—6.5	—5	—4	—4	—5	—3	—3	—2.5	—3	—5	—4.5
16	0	- - -	—3	+2.5	+2.5	+2	+2	+2	+2	+1.5	+1	0	+0.9
17	+1.5	+2	+2	+2	- - -	- - -	- - -	- - -	+2	+2	—4	+5	+1.7
18	+3	+2	—1	+0.5	—3	—1	+2	+2	+2	+2	—1	—5	+0.2
19	—5	—6	—5.5	—4	—3.5	—3.5	—5	—5.5	—6	—6	—6	—6	—5.2
20	—6.5	+6	+5.5	+5.5	- - -	- - -	+5.5	+5	+4	+3	+3	+3	+3.8
21	—3.5	—2.5	—3	—3	—3.5	—4	—3	—3	—3	- - -	- - -	+2	—2.3
22	+3	+4	+4	+6	+6	+6.3	+5	+3	+3	+2	+1.5	—3	+3.4
23	—2.5	—1	- - -	—3	- - -	- - -	—3	—2.5	—2	+1	0	—3	—2.0
24	—5.5	—6	—6.5	—7	—2.5	—3	—3	—5	—7	—7	—7.5	—8	—5.7
25	—10	—9	- - -	—13	—7	—5	—7	—6	—6.5	—6.5	—7	—7.5	—8.0
26	—10	—10	—11	—10	- - -	- - -	- - -	—7	—7	—7.5	—8	—8.5	—8.7
27	- - -	—11	—10.5	—6	- - -	- - -	—3.5	—3.5	—4	—5.5	—5	—4	—6.0
28	—5.5	—8.5	—11	—12	—9.5	—3	+3	+2	+1.5	+1	0	+1	—4.0
29	—2	—1	—1.5	—7	—4	0	+1.5	+1	0	0	0	0	—1.1
30	+1	+2.5	- - -	+3	+3	+3	+3	+2	+2	+1.5	+1	0	+2.1
31	+1	+2	+0.5	+1.5	0	0	—0.5	—3	—0.5	+1.5	+1.5	0	+0.3

Temperature of the air, in shade, observed at Port Foulke, Smith Strait.

November, 1860.

	Day of the month.	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	Mean of 12 values by No. 4
Daily mean by No. 7	1	—1°	0°	0°	—0°.5	0°	+1°	+1°	+0°.5	0°	—0°.5	—1°.5	—3°	—0°.3
	2	—3	—4.5	—4.5	—1.5	—2	—3.5	—4.5	—2	+1.5	+1	+0.5	—1.5	—2.0
	3	—2	—2.5	—4	—2.5	—4	—6.5	—6	—6	—6	—5	—3	—3.5	—4.3
	4	—4	—4.5	—3.5	—2.5	—1	—1	—1	—1	—1	—1	—1	0	—1.8
	5	—1.5	—1.5	—2	—5	—6.5	—7	—7	—7.5	—7.5	—8	—10	—12	—6.3
	6	—11	—8	—11	—10	—10	—8	—9	—9	—8	—9	—10	—10	—9.4
Daily mean by No. 6.	7	—11	—12	—8	—9.5	—10 5	- - - -	—16[1]	—13[1]	—10[1]	—6[1]	—7[1]	—5[1]	—14.8
	8	—3[1]	—3.5[1]	—3[1]	—1.5[1]	0[1]	+4[1]	+2[1]	+2[1]	+2[1]	—1[1]	+4[1]	+5[1]	+0.6
	9	+5	+5[1]	+4.5[1]	+2[1]	+11[2]	—1.5[1]	—1.5[1]	—1[1]	+4[1]	+3[1]	+2[1]	+1[1]	+1.9
	10	+2[1]	+2.5[1]	+2[1]	—4[1]	—5[1]	—6[1]	—6[1]	—6.5[1]	—7.5[1]	—8[1]	—9[1]	—9.5[1]	—4.6
	11	—12[1]	—12[1]	—9.5[1]	—6.5[1]	—5[1]	—4.5[1]	—5.5[1]	—5.5[1]	—5.5[1]	—4.5[1]	—3[1]	—4.2[1]	—6.5
	12	—5.5[1]	—5[1]	—5[1]	—5[1]	—3.5[1]	—3[1]	- - - -	+5[3]	+5	+4.5	+4.5	+4.5	—5.6
Daily mean by No. 4.	13	+4.5	+5	+5	+4.5	+4	+3	+3.5	+4	+5.5	+7	+8.5	- - - -	+5.2
	14	+8	+8.5	+11	+9	+7	+6	+6	+5	+5	+4.5	+4	+2	+6.3
	15	+5	+3	+4.5	+4	+4	+3.5	+1.5	—1	—2.5	—3	—3.5	—9	+0.5
	16	- - - -	- - - -	- - - -	0	0	0	0	0	0	—1	—1.5	—3.5	—1.6
	17	—4	—1	+0.5	0	0	0	0	—0.5	—1	—3	—3.5	—5	—1.5
	18	—7.5	- - - -	- - - -	—1	—1	—1	—4	—3.5	—3	—2.5	—2.5	—5	—3.3
	19	—11	—12	—11	—10.5	—10	—7.5	—7.5	—8	—9	—9	—10	—10	—9.6
	20	—11	—11	—12	—15	—15	—17	—17	—15	—13	—12	—12	—11.5	—13.5
	21	—10	—10	—11	—13	—11.5	—10	—10	—5	—6	—4	—1	0	—7.6
	22	+1	—1	+2.5	+3	+3.5	+1.5	+1	+3	+2	- - - -	- - - -	—4.5	+0.8
	23	+3	+4	+5	+4	+5	+5	+5	+5	+5	+3	+1	0	+3.8
	24	—1	—2	+2	—1	+3	+6	+3	+2.5	+2	+2	+2	+2.5	+1.8
	25	+2.5	+3	+3	+5	+9	+11	+13	+18	+13	+13	+13	+13	+9.7
	26	+11	+4[4]	+7[4]	+7.5[4]	+13[4]	+10	+10	+13	+11	+8	+12	+13	+10.0
	27	+9	+11	+10	+10	+13	+17	+25	+22	+21.5	+21.5	+19	+18	+16.4
	28	+20	+21	+27	+32	+25	+27	+28	+25	+25	+25	+26	+24	+25.4
	29	+24	+23	+21.5	+21	+17	+15	+17	+18	+21	+22	+19	- - - -	+19.8
	30	+19	+17	+17	+16	+15	+15.5	+15	+15	+15	+15	+13	+10	+15.2

[1] Thermometer No. 6.
[2] Thermometer No. 3.
[3] Thermometer No. 4; used till April 5, 1861.
[4] Recorded negative; supposed by mistake.

December, 1860.

Day of the month.	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	Mean of 12 values by No. 4
1	+9°.5	- - - -	+12°	+12°.5	+7°	+8°	+9°	+9°.5	+10°	+9°	+10°	+10°	+9°.8
2	+9	+9°	+9	- - - -	+7	+3.5	—2	—2	—2	0	—1	+1	+3.3
3	0	—5	—11	—13	—11	—9	—13	—14	—14	—12	—12	—15	—10.7
4	—17	—21	—19	—21.5	—19.5	—22	—23	—4	—4	—3.5	- - - -	- - - -	—13.5
5	—4	—2	- - - -	—3	—3	—3	—4	—4	—6	—4	—3.5	—3	—3.5
6	—4	—5	—7.5	—9	—10	—12	—13	—13	—10	—10	—12	—13.5	—9.9
7	—15	—15.5	—16	—16	—13.5	—12	—18	—18	—18	—18	—18	- - - -	—16.3
8	—17	—18	—17	- - - -	—18	—18	—15	—15	—14	—19	—19	—19	—17.2
9	—19	—20.5	—19	—17.5	—19	—19	—17.5	—19.5	—20	—20	—24	—20	—19.6
10	—22.5	—23	—27	—26	—20	—20	—19	—19	—27	—19	—26	—19	—22.3
11	—19	—20	—22	—21	—20	—19	—8	—8	—9	—10	—11	—11.5	—14.9
12	—11	- - - -	—10	—14	—20	—16	—19	—18	—19	—15	—16.5	—19	—15.7
13	—18	—17	—16	—17	—8	—8.5	—10	—10	—11	—11.5	—12	—9	—12.3
14	—12	—13.5	—13	—16.5	—16.5	—17	—18	—18.5	—22	—21	—22	—17	—17.3
15	—16.5	—16	—8	—7	—7	—7	—7	—8	—8	—9	—9	—11	—9.5
16	—12.5	—12	—13	—8	—8	—7.5	—7	—8	—10	—13	—14	- - - -	—9.9
17	+2	—7	—5	—4	—4	—4	—3	—3	—3	—2	—1.5	- - - -	—2.9
18	+1.5	—1	—1	—2	—0.5	—1	0	—4	—6	—2	+1	—1	—1.3
19	—3	—3	—2.5	—2	—2	—2	—3	—3	—4.5	—6	- - - -	—4	—3.3
20	—3	—5	—5.5	—6	—7	—7	—7	—8	—7.5	—8.5	—10	—11	—7.1
21	- - - -	—15	—15.5	—18	—14.5	—14	—10	—10	—14	—19	—19	—20	—15.2
22	—20	—20	—20.5	—21	—21	—19	—20	—20	—19.5	—17.5	—10	- - - -	—17.9
23	—3	—2	—1	+1	+1	+1	+1	+2	- - - -	- - - -	+10	+9	+2.6
24	+12	+9	- - - -	+2	+2	+3	+3	+3	—2	—3	—4	—4.5	+2.2
25	—5	—9	—7	—7	—7	—9.5	—10	—10	—12	—13.5	—14	—11	—9.2
26	—11	—13	- - - -	—13	—12.5	—12	—12.5	—12.5	—12.5	—13	- - - -	—15	—12.8
27	—15.5	—16	- - - -	—18	—18	—18	—18.5	—17	—18	—20	—20	—18	—17.8
28	—18	- - - -	- - - -	—19	—14	—11	—7	—7.5	—8	—8.5	—16	—9	—12.9
29	—11	—11.5	- - - -	—13.5	—14	—11	—9.5	—10	—11	—14	—17	—21	—13.0
30	—20	—24	- - - -	—23	—20	—24	—22	—20	—20	—20	—20	—15	—21.0
31	—20	—18	—21	—21	—22.5	—22.5	—24	—11	—17	—17	—19	—14.5	—19.0

Temperature of the air, in shade, observed at Port Foulke, Smith Strait.
January, 1861.

Day of the month.	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	Mean of 12 values by No. 4.
1	—19°	—20°	—19°	—20°	—21°	—23°	—20°	—23°	—23°.5	—24°	- - - -	—25°	—21.°8
2	—25	—27	—23	- - - -	—26	—27	—25	—25	—25	—25.5	—20°	—20	—24.4
3	—21.5	—19	—25	—25	—27	—30	—30	—30	—31	—31	—31	—32	—27.7
4	—30	—26	—28	—29	—29	—28.5	—29.5	—28	—22	—15	—15	—16	—24.7
5	—16	—17	—18	—21	—20	—20.5	—26	—30	—28	—26.5	—29	—30	—23.5
6	—31	—33	—34	—32.5	—32	—32.5	—32.5	—17	—16	—15.5	—22	—20	—26.5
7	—22	—24	—25.5	—21	—17	—16	—18.5	—17	—14.5	—16	—25	—27	—20.3
8	—25	—18	—18	—11.5	—11	—14	—14	—14.5	—15	—19	—21	—18	—16.6
9	—20	—18	—16	—17.5	—13	—11	—17	—17.5	—18	—17	—16	—21	—16.8
10	—21.5	—23	—24	—23	—20.5	—19	- - - -	—19	—17.5	—17	—16	—10	—19.1
11	—9	—8	- - - -	—10	—10	—10	—7	—11	—11.5	—13	—14	—13	—10.5
12	—13	—15	—16	—13	—14	—13.5	—13	—15	—18	—19	—17	—9	—14.6
13	—10	—12.5	—14	—17	—17	—19	—19	—18.5	—19	—16	—13	—15	—15.8
14	—17	—12	—12	—4	—5	—8.5	—7	—7	—6.5	—7.5	—4	—7	—8.1
15	—11	—13	—17	—16	—14	—15	—22	—21	—21	—20.5	—20	—20	—17.5
16	—21	—22	—22	—29	—28	—28	—28	—29	—29	—25	—23.5	—18	—25.2
17	—19	—22	- - - -	—18	—18	—18	—20	—23	—25	—24	—27	—28	—21.8
18	—30	—30	- - - -	—28	—30	—30	—26	—25	—25	—20	—14	—15	—25.2
19	—17	- - - -	—14	—18	—20	—21	—21.5	—22.5	—24	—26.5	—28	—28	—21.3
20	—28.5	—29	—32	—29.5	—32	—32	—32	—32.5	—30	—30	—27	—28	—30.2
21	—29	—30	—32	—27.5	—24	—25	—25	—26	—26.5	—25	—26	—26.5	—26.9
22	—29	—26	—26	—25	—25	—28	—27.5	—27.5	—28	—30.5	—32	—33	—28.1
23	—34	—34	—36	—34	—38	—38.5	—38	—38.5	—39	—35	—43 ?	—37	—37.1
24	—32	—30	—28	—24	—22	—22	—22	—21	—26	—28	—33	—37	—27.1
25	—39	—40	—42	—39	—35.5	—25	—26	—24	—23.5	—25	—25	—27	—30.9
26	—26.5	—25	—27	—24	—26	—25	—25	—30	—28	—27.5	—27	—26	—26.4
27	—27	—25	—24	—22.5	—17	—17.5	—18	—18	—19	—20	—17	—19	—20.3
28	—19	—19.5	—18	—18	—20	—19.5	—19	—25	—23	—25	—28	—29	—21.9
29	—24.5	—21	—21	—22	—24	—25	—22	—25	—26.5	—28	—26	—25	—24.2
30	—26	—26	—27	—26	—25.5	—25	—27	—25	—27	—27	—28.5	—29	—26.6
31	—35	—36	—36	—33	—34	—32	—31.5	—33	—30	—30	—27	—28	—32.2

On the 23d, 10 A. M., mercury in a glass vial froze on the ice in front of the ship. Thermometer No. 9 remained stationary at —36°.8 at the observatorv. Mercury thawed at 2 A. M. January 24. January 25, Thermometer No. 9, mercury froze at —36°.5.

February, 1861.

Day of the month.	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	Mean of 12 values by No. 4.
1	—30°	—29°	—26°	—27°	—22°.5	—15°	—9°	—10°	—12°	—15°	—17°	—14°	—18°.9
2	—13	—8	—9	—12	—12	—12	—17	—19	—19	—19.5	—20	—24	—15.4
3	—26	—21	—20	—19	—21	—22.5	—24.5	—30.5	—35	—35	—35	—29	—26.5
4	—32	- - - -	—26	—19	—18	—18	—18	—18	—18	—18	—16	—19	—20.8
5	—16	—25	—20	—24	—20	—20	—19	—19	—20	—17	—19	—24	—20.2
6	- - - -	—26	—26	—24	—18	—17.5	—19	—18	—17.5	—15	—16	—26	—20.7
7	—27	—26	—27	—29	—27	—27	—21	—27	—28	—29.5	—28	—30	—27.2
8	—28	—28	—24	—15.5	—24	—24	—24	—24.5	—25	—24	—23.5	—19	—23.6
9	—18	- - - -	—16	—21.5	—22	—20	—18	—20	—21	—22	—20	—24	—20.0
10	—25	—25	—21	—22	—22	—23.5	—26	—25.5	—25	—25.5	—26	—25	—24.3
11	—26	—20	—19	—17	—17	—17	—17	—19	—17	—19	—18	—18	—18.7
12	—17	—16.5	—18	—17	—17	—18	—20	—20.5	—21	—21	—20	—28	—19.5
13	—26	—29	—33	—32	—31	—31	—35	—32	—32	—27	—25	—28	—30.1
14	—28	—29.5	—31	—25	—30	—29	—29	—27.5	—27	—27	—27	—29	—28.3
15	—31	—32.5	—34	—30	—31.5	—32.5	—31.5	- - - -	- - - -	- - - -	—32	—32	—31.9
16	—34	—37	—38	—31	—31	—30.5	—29	—28.5	—28	—29	—30	—26	—31.0
17	—29	—33	—35	—31	—31	—30	—18	—25	—25	—26	—28	—23.5	—27.9
18	—23	—24	- - - -	—25	—26	—26	—25	—26	—20.5	—23	—24	—21	—24.0
19	—23	—27	—26	—27	—30	- - - -	—27	—31	—32	—30.5	—29	—30	—28.4
20	—30	- - - -	—14	—10	—11.5	—13	—11	- - - -	—13	—15	—16	—20	—15.6
21	—22	—25 ?	—9	—8	—8	—10	—10	—11	—11.5	—13	—10	—14	—12.6
22	- - - -	—19	—19	—17	—16	—16	—16.5	—15	—16	—16	—21	—22	—17.5
23	—20	—20	—25	—26	—20	—16	—10	—9	—11.5	—12.5	—15	- - - -	—16.7
24	—16	—17	—16	—17	—17.5	—18	—17	—19	—19	—19	—17	—22	—17.9
25	—21	- - - -	—18	—17	—14	—16	—16	—18	—18	—18	—19	—19	—17.8
26	—21	—24 ?	—25 ?	—14	—16.5	—17	—20	—18	—20	—19	—18	—19	—19.3
27	- - - -	—20	—18	—20	—21	—23	—19	—21	—21	—21.5	—22	—21	—20.6
28	—24	—25	—25	—19	—20	—19.5	—16.5	—18	—19	—20	—14	- - - -	—19.6

February 18, sun seen above the horizon; February 25, 2 P. M., sun shone on deck; and at 2½ P. M., on observatory.

Temperature of the air, in shade, observed at Port Foulke, Smith Strait.

March, 1861.

Day of the month.	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	Mean of 12 values by No. 4.
1	—16°	—16°	—19°	—23°	—24°	—23°	—21°	—22°.5	—20°	—18°	—14°	—8°	—18°.7
2	—9.5	—9.5	—9	—9	—9.5	—9	—9	—13	—14	—14	—13	—15	—11.1
3	—14	—12	—16	—15	—14	—12	—11	—17	—14	—14.5	—14	—17	—14.2
4	—22	- - - -	—23	—19	—19	—19	—15.5	—20	—22	—24	—23	—23.5	—21.0
5	—26	—27	—29	—29	—27.5	—29	—30	—32	—32	- - - -	—33	- - - -	—30.1
6	—35	—35	—35	—32	- - - -	—28	—22.5	—23.5	—23.5	—25.5	—30	- - - -	—29.0
7	—25	—23	—22	—24	—23	—23	—18	—19	—21	—22	—22	—22.5	—22.0
8	—23	—27	—19	—13	—14	—14.5	—10	—13	—12	—11.5	—11	—11	—14.9
9	—14	—14	- - - -	—17	—15	—12	—4	—7	—9	—10	—12	—15	—12.0
10	—11	- - - -	—15	—17	—16	—15	—12	—12	—10	—10	—10	—11	—12.7
11	- - - -	—14	—10	—12	—13	—13.5	—10	—11.5	—14	—15	—15	- - - -	—13.0
12	—16	—16	—18	—15	—15	—14	—13	—13	—14	—15.5	—16	—20	—15.5
13	—20	—23	—25	—24.5	—18	—18	—12	—17	—27	—28	—31	—31	—22.9
14	—31.5	—34	—30	—20	—25	—22	—20	—21	—25	—25	—25	—28	—25.5
15	—31	—32	- - - -	—27	—28	—26.5	—16	—20	—24	—25	—32.5	—34	—27.1
16	—35	—38	—35	—32	—31	—29	- - - -	- - - -	—22	—20	—18	—28	—28.2
17	—20	—20	—24	—25	—27.5	- - - -	—21[1]	—23[1]	—28.5	—30	—31	—33.5	—25.0
18	—34	—34	—31	—16	—16.5	—17	—15[1]	—15.5[1]	- - - -	—23	—27.5	—17	—21.6
19	—18	—19	—19	—22	—20	—18.5	—17.5[1]	—19[1]	—20	—14	—15	—20	—18.1
20	—21	—27	—14	—13	—15	—15	—14[1]	- - - -	—21.5	—25	—25	—27	—19.3
21	—29	—28	- - - -	—28	—25	—22	—21	—24[1]	—21	- - - -	—25	—29	—25.0
22	—31	- - - -	—33	—24.5	—25	—26	—22[1]	—21.8[1]	—28	—31	—31	—32	—27.6
23	- - - -	—30	—30	—30.5	—28	—28[1]	—21[1]	—20[1]	—27	—30.5	—33	- - - -	—27.8
24	—35	—37	—38.5	—34	—32	—30[1]	—26[1]	—27[1]	—28	—31.5	—32	—31	—31.0
25	—28	—22	—20	—19.5	—14	—11	—18[1]	—19[1]	- - - -	—22	—25	—29	—20.1
26	—30	—32	—32	—30	—30	—28[1]	—22[1]	—16[1]	—13	—13	—17	—21	—22.9
27	—24	—23	- - - -	—12	—11	—12	—10	—14	—9	—9	—14	—10	—13.8
28	—9	- - - -	—5	—2	—5	—5	—5.5	—2	—4.5	—5	—7	—8	—5.4
29	- - - -	—11	—19	—16	—12	—10	—6	—8.8	—8	—7.5	—8.5	- - - -	—10.5
30	—11	—12	—12	—9	—8	- - - -	—7[1]	—7	—6	—7.5	—9.5	—16	—9.1
31	—19	—22	—21	—17.5	—11	—10[1]	—6[1]	—1	—6	—11	—15	—17	—12.7

March 16, 2 P. M., moved the thermometers from the front to the rear of the meteorological box on shore, to protect them from the sun.

[1] Readings by thermometer No. 3.

April, 1861.

Means referred to No. 13.

Day of the month.	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	Mean of 12 values by No. 13.
1	—15°	—18°	—22°	—19°	—19°.5	—15°[1]	—10°5[1]	- - - -	—11°	—15°	—16°	—18°	—18°.4
2	—16	—17	- - - -	—17.5	—16	—15.5	—15.5	—16°.5	—17	- - - -	—16	—18	—20.0
3	—17	- - - -	—21	—19	—23	—22.5[1]	—18[1]	—17	—20.5	—18.5	—21	—22	—23.5
4	—22	—23	—21	- - - -	—17	- - - -	—12.8[1]	- - - -	- - - -	—19	—22	—22	—22.0
5	—20	—17.5	- - - -	—11	—13	—12	—13[2]	—12	—12	—13	—15	—16	—15.6
6	—15.5	—15	—13	—10	—10	—12.5	—12.5	—14	—15.5	—15.5	—19	—23	—14.6
7	—23	—25	- - - -	—20	—21	—21.5	—20	—24	—24	—23.5	—23	—23	—22.5
8	—25	—27.5	—25	—24	—22	—21	—20	—21	—22	- - - -	—23.5	—25	—23.2
9	—24	—24	- - - -	—20	—20	—18.5	—17.5	—18.5	—20	—19.5	—19	—19	—20.2
10	—20	—19	- - - -	—15	—15	—16	- - - -	—18.5	—21.5	- - - -	—27	—27	—19.8
11	—26.5	—27	- - - -	—26	—26	—24	—21.5	- - - -	—19.5	—18	—17	—16	—22.4
12	—14	—14	- - - -	—11.5	—7	—6	—5	—8	—10	—11	—15	—17	—10.9
13	—15	—15.5	- - - -	—11.5	—7	—10	—10	—11	—11	—11	—12	—12	—11.6
14	—13	—13	—13	—13	—13	—11	—11	—11	—11.5	—12	—15	—15	—12.6
15	—13	—11	—11	—11	—11	—10	—11	—10	—13	—15.5	—18	—18	—12.7
16	—16	—16	- - - -	—10	—8	—9	—7	—8	—8	—8	—11	—11	—10.4
17	—12	—12	- - - -	—10	—8	—3	—0.5	—0.5	—1	+1	—2	—3.5	—5.2
18	—3	—4	- - - -	0	+1	+1	+1	—2	—4	- - - -	—8.5	—10	—3.1
19	—10	—10	- - - -	+1	+2	+2	+2	+3.5	+5	+5	+1	—1	—0.3
20	—7	—8	- - - -	+1	+2	+4	+4	+3.5	+4	+5	+3	+3	+0.9
21	+2.5	+2	+2	+1.5	0	—1.5	—3.5	—5	—6.5	—8	—8.5	—9	—2.8
22	—8.5	—8	- - - -	—2.5	—2.5	—2.5	—3	—4	—4	—4	—8	—8	—5.0
23	—8.5	—9	—6.5	—2.5	—2.5	—2.5	—4	—4	—4	—4	—4	—4	—4.6
24	—5.5	—5.5	—3	—2	0	+1	+1	0	—0.5	—4	—4	—5.5	—2.3
25	—6	—6.5	—7	—8.5	—10	—9.5	—9	—9.5	—10	—10	—10.5	—10.5	—8.9
26	—14	—16	—13	—9	—6.5	0	—1	—1	—3	—5.5	—9.5	—11	—7.5
27	—8	—7	—6	—6	—6	—6.5	—6	—6	—6	—6.5	—7	—7	—6.5
28	—9	—8	- - - -	—6	—4.5	—3	—3.5	—5	—6.5	—8	—9.5	—8	—6.5
29	—7.5	—7.5	- - - -	—4	—3.5	—1.5	—0.5	0	+1	+1.5	+2	+2.5	—1.9
30	0	—1	+1.5	+2.5	+4	+6	+8	+6	+4.5	+4.5	—1.5	+2	+3.0

[1] Readings by thermometer No. 3.

[2] All the following readings by No. 13; thermometer No. 4 was taken in and No. 13 hung on the portside, forward, facing east, and in the shade.

Temperature of the air, in shade, observed at Port Foulke, Smith Strait.

May, 1861.

Day of the month.	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	Mean of 12 values by No. 13.
1	2°	2°.5	---	4°	4°.5	5°	6°	5°	4°.5	2°	0°.5	0°	+3°.3
2	1	1.5	1.5	2	2	2.5	—1	—1	6	9	7	4	2.9
3	5.5	7.5	---	12	12	10	9.5	8.5	8	7.5	6	3.5	8.3
4	5.5	7	---	10.5	13	13	15	15.5	16	15.5	15	14	12.4
5	13	13	12.5	12	14	17	17	11	12	12.5	14	13	13.4
6	12	19	23	24	24	24	24	25.5	25	22	17	19	21.5
7	15	20	---	19[1]	25	26	26	24	20.5	19	19.5	18	20.8
8	20	20	21	25.5	28	30	30	31.5	29	27	27	26	26.2
9	26	26	27	34.5	33	31	29	28	27.5	24	---	22	27.6
10	25	22	---	27	31	33.5	35	38	36	34	30.5	31	30.6
11	24	25	---	31	30	31	30	29.5	29.5	30	27.5	27	28.5
12	25	32	34	---	32	32	35	38	40	31	27	27	32.2
13	28	30	---	38	38.5	40	---	---	36	34	---	29	34.6
14	27	28	---	34	35	35	37	36.5	39	30.5	27	25.5	32.1
15	26	32	34	33	37	33	34	30	30	31	32	29	31.8
16	29	29	30	33	35	34.5	34.5	33.5	32	27	27	22	30.5
17	25	23	21	27	29	31	28.5	29.5	24	---	24	20	25.5
18	19	20	21	19	17.5	19	19.5	19	20	18	16	17	18.8
19	13	14	12	20	20	16	17	17	16	15	12.5	14	15.5
20	13	16	10	14.5	14	17	19	17	16	17	16	15	15.4
21	15	16	17	---	20	22	23	21.5	23	19.5	18.5	18	19.3
22	16	20	---	28	23.5	23.5	23	21	20	19.5	17	10	20.5
23	13	16	---	22	22	22	22	21	20	19	17.5	18	19.3
24	19	24	21	21.5	23	23	23	23	23	23	23.5	22	22.4
25	21	20	22	24	28	29	26	25	22.5	21	20	19	23.1
26	19	27	29	30	30	29.5	29	37	36	31	26.5	25	29.1
27	26	27	30	32.5	36	39	31.5	30	31	30.5	27.5	27	30.7
28	22	22	28	37	30.5	28.5	28	32	31	29.5	26.5	30	28.8
29	24	29	---	26	28	30	29	28	27.5	25	24	23	26.8
30	23	23	25	23.5	24	24	24	23.5	23.5	20.5	19	18	22.6
31	16.5	16.5	17	18	18	21.5	20.5	19.5	19.5	19.5	19	18	18.6

May 9th, the thermometers on shore were placed in a large box to protect them from the rays of the sun. May 23d, thermometers brought on board.

[1] Recorded by thermometer No. 3.

June, 1861.

Day of the month.	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	Mean of 12 values by No. 13.
1	18°	17°	20°	19°.5	19°.5	20°	22°	21°	21°	20°	19°	18°	+19°.6
2	17	18	18	20	21	21	21.5	21.5	20.5	20	18	18	19.5
3	18	16	18	18.5	19.5	20	21	21.5	21.5	21	20	21	19.7
4	21	22	---	23	23	25.5	25	27	28	29	27.5	28	25.1
5	27	28	29	27.5	28	29	30	31.5	28	25	23	21	27.3
6	21	23	25	26	27.5	27	28	29	27	26	24	19	25.2
7	19	26	26	27	32	34	34	34	32	25	25	19.5	27.8
8	25	26	31	28	29.5	30	29	---	29	28	24	---	27.5
9	22	28	---	32	38	40	41	42.5	39	---	30.5	31	34.1
10	28	31	31	31	---	36	36	36	33	31	28.5	30	32.1
11	31.5	30	---	33	33	35.5	36	36	35.5	32.5	32	31	33.1
12	31	30.5	31	32	34	---	33	33	34	34	---	32	32.6
13	31	36	34	33	35	33	33	32	32	32	32	31	32.8
14	30	34	37	35	39	41	41	35	33	31	31	30	34.8
15	30	35	37	---	---	---	39	33	33	33	33	30	34.8
16	33	33.5	31	33[1]	33	33	33[1]	32	32	32	33[1]	33	32.3
17	33	32	31.5	32	34	35	36	34.5	35	34	34	35	33.8
18	32	---	33	36	36.5	34	34.5	35	34.5	34.5	33	35	34.2
19	34	35	34	35.5	35	34	35.5	34	33	32	33	33.5	34.0
20	33	34	35	35	35	40	40	40	39.5	---	35	32	36.3
21	32	35	34.5	39	43	44	49	49	43	43.5	35	---	40.0
22	32	---	41	42	43	43	---	43.5	46.5	45	42	42	41.6
23	43	40	41.5	39	40	44	47	46	42	43	38	38	41.8
24	37	37	39	39.5	40	40	43	43	43	39	---	37	39.6
25	37	39	39	39.5	37.5	39	39	39	39.5	40	40.5	39.5	39.0
26	39	39	38	38	38	39	39	36	37	38	39	38	38.2
27	37	38	38	38	38	39	39	37	36	34	34	33	36.8
28	33	33	34	36	36	36	38.5	39.5	40	39.5	38.5	35	36.6
29	35	34	35	37	38	36	36	36	37	39	35	35.5	36.1
30	34	35	35	37	36.5	35	38	37	37	36.5	37	35	36.1

[1] Recorded by No. 3.

Temperature of the air, in shade, observed at and near Port Foulke, Smith Strait.
July, 1861.

Day of the month.	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	Mean of 12 values by No. 13.
1	36°	37°	- - -	40°	40°	41°	41°.5	38°	38°	37°	40°	37°	+38°.7
2	35	35	35°	33	34	34	40	38	39	34	43	35	36.3
3	- - -	38	39	41	43	47	51.5	46.5	44	43.5	39.5	- - -	42.5
4	42	44	40	39	- - -	39.5	39	- - -	36.5	33.5	33	32	38.0
5	32	35	39	39	49	49	63	45	43.5	41	37	36	42.4
6	36	36	39	39	39	42	48	56	47	43	38	36	41.6
7	35	39	- - -	43	50	48	48	49	47	48	44	44	44.7
8	42.5	41.5	37	40	39.5	40	40	40	40	38.5	39	38	39.7
9	38	42	- - -	44	47	- - -	47	46	46.5	40	42	41	43.6
10	40.5	41	43	43	44	45	41	43	43	- - -	36	36	41.2
11	36	31	- - -	39	38.5	38	42	39	40	42	45	43	39.0
12	48	40	- - -	54	56	56	55	61	- - -	44	- - -	- - -	49.5
13	36	36	- - -	34	34	34.5	37	47	49	44	38	35	38.3
14	34	37	40	43	44	37[1]	39	44	46.5	44	53	37	41.5
15	40	44	39	48	48	40	45	40	40	43	43	39	42.4
16	36.5	35.5	36	35	36	36	36.5	36	35	36	36	35.5	35.8
17	35	35	35.5	36	37	39	42	41.5	- - -	43	38	37	38.4
18	39	39	39.5	40	40	42	42	41	42	41	38	38.5	40.2
19	38	38	41	42	39	39	40	39	40	38	38	38	39.2
20	39	41	40.5	42	48	38	41	- - -	38	37	36	34	39.5
21	35	35	35	35	36	40	39	38.5	40	36	35	34	36.5
22	34	35	37	38	42	40	38	37	36	34	34	34	36.6
23	32	32	32	32.5	33	34	- - -	38.5	- - -	37.5	35	34	34.6
24	35	36.5	38	39	- - -	34	- - -	34	32.5	32.5	32.5	32	34.7
25	31	31	32	32	32.5	33	33	33	34	35.5	34	34.5	33.0
26	35	36	36	38	38	40.5	43	46	43	47	53	40	41.3
27	36.5	33.5	34.5	35	41	43	44.5	43	43.5	59	53.5	48.5	43.0
28	50	53.5	56	63	65	- - -	- - -	- - -	- - -	50	47	47	55.1
29	54	50	45	51	45	47	56	60	46	47	59	53	51.1
30	49	47	44	48.5	45	50	45	48	44.8	40	36	34	44.3
31	34	35	35	35	36	37	37	38.5	38	35	32.5	32.5	35.5

[1] Pulled out of Port Foulke. The original record after July 14, noon, is by "sea days," or astronomical reckoning, which is here changed to civil reckoning.

Notes to preceding Record.

[1]November, 1860. The five readings of the 7th, recorded by No. 7, and the five readings of the 12th, recorded by No. 4, as well as the reading by No. 3, on the 9th, were referred to No. 6 by application of the corrections —10°.3, —11°.7, and —10°.5, respectively.

March, 1861. The readings by No. 3 were referred to No. 4 by applying the correction (with sign reversed) as made out from the comparisons.

April, 1861. All the readings preceding 2 P. M. on the 5th, taken by thermometer No. 4, were referred to No. 13.

Daily Mean Temperature of the Air, in shade, observed at Port Foulke.

Twelve observations a day, taken at equi-distant intervals, give so nearly the same result as hourly observations (within less than ±0°.04) that no further correction is required. The values of the daily mean temperature, given in the table, were obtained by adding the correction for error of graduation to the daily means as set out in the preceding record.

[1] Occasional omissions in the record were supplied by interpolation before any means were taken. As this interpolation was made in the most simple manner, the interpolated values themselves need not be shown.

Day of the month.	1860.				1861.						
	Sept.	Oct.	Nov.	Dec.	Jan'y.	Feb.	March.	April.	May.	June.	July.
1	+23°.4	+16°.1	+0°.7	+9°.9	—24°.8	—21°.7	—21°.5	—17°.7	+3°.3	+21°.3	+39°.1
2	22 1	21.4	—1.0	+2.7	—27.6	—17.8	—13.1	—19.0	2.9	21.1	37.3
3	23.9	21.4	—3.3	—12.7	—30.9	—29.7	—16.6	—22.1	8.9	21.4	41.8
4	21.2	25.5	—0.8	—15.8	—27.9	—23.7	—23.9	—20 6	13.5	26.9	38.6
5	24.8	23.0	—5.3	—4.8	—26.7	—23.0	—33.4	—15.5	14.6	29.0	41.8
6	28.7	22.2	—8.4	—11.8	—29.7	—23.5	—32.2	—14.6	23.2	27.0	41.2
7	25.9	24.7	—3.4	—18.8	—23.1	—30.4	—25.0	—21.1	22.5	29.4	43.6
8	24.4	28.1	+11.2	—19.8	—19.2	—26.8	—17.3	—21.8	27.9	29.2	39.8
9	25.9	26.2	+12.4	—22.4	—19.4	—22.8	—14.1	—19.1	29.3	35.3	42.7
10	26.4	16.0	+6.6	—25.3	—21.9	—27.5	—14.9	—18.9	32.0	33.5	40.8
11	30.5	11.9	+4.8	—17.3	—12.5	—21.5	—15.3	—21.0	30.0	34.4	39.3
12	26.8	12.1	+5.7	—18.2	—17.0	—22.3	—18.0	—11.6	33.6	33.9	47.9
13	25.6	+6.5	+4.7	—14.5	—18.3	—33.4	—26.0	—12.2	35.8	34.1	38.8
14	24.0	—1.4	+5.9	—19.9	—9.8	—31.5	—28.7	—13.0	33.5	36.0	41.1
15	25.4	—3.5	—0.3	—11.4	—20.2	—35.3	—30.3	—13.1	33.2	36.0	41.8
16	30.6	+1.9	—2.7	—19.8	—28.4	—34.3	—31.4	—11.2	32.0	33.7	36.9
17	24.6	+2.7	—2.5	—4.1	—24.8	—31.1	—28.2	—5.8	27.3	35.0	38.8
18	21.2	+1.2	—4.5	—2.3	—28.4	—27.2	—24.6	—3.6	20.4	35.6	40.1
19	18.4	—4.2	—11.4	—4.5	—24.2	—31.6	—20.8	—0.6	16.9	35.3	39.4
20	19.7	+4.8	—15.8	—8.7	—33.5	—18.1	—22.1	+0.7	16.8	37.3	39.6
21	23.7	—1.3	—9.2	—17.6	—30.1	—14.8	—28.2	—3.3	20.9	40.0	37.5
22	26.4	+4.4	0.0	—20.6	—31.3	—20.1	—30.8	—5.6	22.2	41.2	37.6
23	17.3	—1.0	+3.3	+2.0	—40.5	—19.3	—31.0	—5.2	20.9	41.4	35.8
24	20.0	—4.7	+1.1	+1.5	—30.3	—20.6	—34.3	—2.7	24.1	39.7	35.9
25	20.2	—7.0	+9.8	—11.0	—34.2	—20.5	—22.9	—9.8	24.9	39.3	34.3
26	18.0	—7.7	+10.1	—15.1	—29.6	—22.1	—26.0	—8.3	30.6	38.7	40.9
27	18.5	—5.0	+16.6	—20.5	—23.1	—23.5	—16.2	—7.2	32.2	37.8	42.2
28	19.4	—3.0	+25.6	—15.2	—24.9	—22.4	— 6.8	—7.2	30.3	37.6	53.1
29	9.7	—0.1	+20.0	—15.3	—27.4		—12.5	—2.3	28.5	37.2	49.4
30	11.4	+3.1	+15.4	—23.9	—29.8		—10.9	+3.0	24.4	37.2	43.2
31		+1.3		—21.8	—35.6		—14.9		20.2		36.6
Mean,	+22.60	+7.60	+2.84	—12.81	—25.97	—24.88	—22.32	—11.01	+23.77	+33.85	+40.54

Annual Fluctuation of the Temperature of the Air.

The annual fluctuation of the temperature at Port Foulke is represented by the above monthly means and an interpolated value for the month of August. For the purpose of comparison and interpolation the observed mean temperatures at Van Rensselaer Harbor[1] and at Port Kennedy[2] are placed together with the corresponding values at Port Foulke. The interpolated temperature for August is obtained as follows: August warmer than June at Van Rensselaer Harbor, 1°.70; at Port Kennedy, 1°.84; mean, 1°.77; which, added to the observed temperature of June at Port Foulke, gives 35°.62 for the temperature of August. In the same manner the comparison of the July and August temperature gives August colder than July 4°.77, hence temperature of August 35°.77. Again, the comparisons with September give for the preceding month 37°.55, giving to this last value the weight one-half, and to the others the weight one each, the temperature for August becomes 36°.07, all expressed in degrees of Fahrenheit's scale.

[1] Middle of page 29 of discussion of Dr. E. K. Kane's Observations.

[2] Second table of page 20 of discussion of Sir F. L. M'Clintock's Observations.

	Port Foulke. 1860–61. $\phi = 78^\circ 18'$ $\lambda = 73\ 00$	Van Rensselaer. 1853–4–5. $78^\circ 37'$ $70\ 53$	Port Kennedy. 1858–59. $72^\circ 01'$ $94\ 14$
January	—25°.97	—28°.22	—34°.40
February	—24.88	—26.43	—37.08
March	—22.32	—34.88	—18.22
April	—11.01	—10.35	—2.92
May	+23.77	+13.45	+15.04
June	+33.85	+30.12	+35.11
July	+40.54	+38.19	+40.12
August	(+36.07)	+31.82	+36.95
September	+22.60	+13.45	+25.43
October	+7.60	—3.58	+7.44
November	+2.84	—21.95	—11.60
December	—12.81	—31.12	—33.63
Spring	—3.19	—10.59	—2.04
Summer	(+36.82)	+33.38	+37.40
Autumn	+11.01	—4.03	+7.09
Winter	—21.22	—28.59	—35.04
Year	(+5.86)	—2.46	+1.85

At Port Foulke every month, excepting April, was warmer than the corresponding month at Van Rensselaer Harbor, and on the average of the year the temperature was 8°.32 milder than at the latter place, and 4°.01 milder than at Port Kennedy. Port Foulke agrees more nearly with Port Kennedy in not showing the excessive cold spring and cold autumn of Van Rensselaer, but differs most conspicuously from either by a mild winter. The summer temperatures differ least, as the presence of ice and perpetual snow tends to keep the temperature near the freezing point. The range of the summer and winter mean temperature is 58°.0, at Van Rensselaer Harbor 62°.0, and at Port Kennedy 72°.4. This difference between the extreme seasons is gradually increasing as we proceed northward on the west coast of Greenland, thus—

Jacobshaven	$\phi = 69^\circ\ 12'$	difference	41°.6
Omenak	70 41	"	45.8
Upernavik	72 47	"	47.7
Wolstenholm Sound	76 33	"	66.7
Port Foulke	78 18	"	58.0
Van Rensselaer Harbor	78 37	"	62.0

The difference of Wolstenholm Sound appears to be anomalous and must be accounted for by local influences.

To express the observed temperature fluctuations analytically by means of Bessel's periodic function, requires, strictly, months of equal length, especially when the annual range of temperature is considered. This is effected in the present investigation[1] by dividing the year into twelve normal months of 30.42 (nearly) days, and

[1] In the meteorological discussions for Van Rensselaer Harbor and Port Kennedy an attempt was made to do this by an approximate method, but the following strict process, now pursued, will not be found too laborious. For common years: Retain only 0.42 of January 31 as belonging to that

of 30.5 days for common and leap years respectively. New monthly sums and means were then taken.

In the formula[1]

$$T = A + B_1 \sin(\theta + C_1) + B_2 \sin(2\theta + C_2) + B_3 \sin(3\theta + C_3) + \ldots\ldots$$

T represents the temperature for any part (month or day) of the year, and the angle θ counts from January 1st (0^h A. M.) at the rate of 30° a month or 59′.2 and 59′.0 a day for common and leap years.

For Port Foulke we have:—

$$T = +6^\circ.06 + 33^\circ.11 \sin(\theta + 242^\circ\ 14') + 6^\circ.32 \sin(2\theta + 119^\circ\ 3') + 0^\circ.74 \sin(3\theta + 318^\circ)$$

For comparison, the expression for Van Rensselaer Harbor was found:—

$$T = -2^\circ.20 + 35^\circ.59 \sin(\theta + 251^\circ\ 43') + 6^\circ.72 \sin(2\theta + 69^\circ\ 47') + 3^\circ.20 \sin(3\theta + 17^\circ)$$

And for Port Kennedy:—

$$T = +2^\circ.02 + 39^\circ.20 \sin(\theta + 249^\circ\ 05') + 0^\circ.80 \sin(2\theta + 256^\circ\ 56') + 1^\circ.06 \sin(3\theta + 275^\circ)$$

The observed and computed mean monthly temperatures compare as follows; the months are of equal length, and it will be seen that the temperatures of the actual months differ but little from those of the normal months.

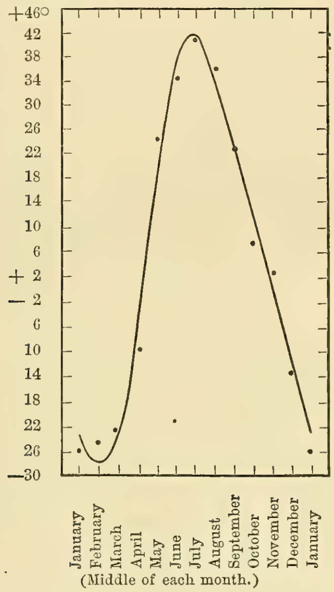
Normal month.	Port Foulke, 1860–61.		
	Observed temperature.	Computed temperature.	Difference O.—C.
January	—25°.97	—22°.94	—3°.03
February	—24.63	—27.90	+3.27
March	—22.41	—22.79	+0.38
April	—9.95	—5.25	—4.70
May	+24.81	+18.98	+5.83
June	+34.52	+37.43	—2.91
July	+40.53	+41.56	—1.03
August	(+36.07)	+33.88	+2.19
September	+22.50	+22.27	+0.23
October	+7.46	+10.87	—3.41
November	+2.96	—0.72	+3.68
December	—13.18	—12.67	—0.51
Seasons and year.			
Spring	—2.52	—3.02	+0.50
Summer	(+37.04)	+37.62	—0.58
Autumn	+10.97	+10.81	+0.16
Winter	—21.26	—21.17	—0.09
Year	+6.06	+6.06	0.00

month (and consequently cast over 0.58 of it to February); include with February, March 1, and 0.83 of the second; with March, April 1 and 0.25 of the second; with April, May 1 and 0.67 of the second; with May, June 1 and 0.08 of the second; with June, July 1 and 0.50 of the second; with July 0.92 of August 1; with August 0.33 of September 1; with September 0.75 of October 1; with October 0.17 of November 1; with November 0.58 of December 1. For leap years: Retain only 0.5 of January 31, casting the other half into February; with February include March 1; with March 0.5 of April 1; with April May 1; with May 0.5 of June 1; with June July 1; with July 0.5 of August 1 (leaving the other half to be counted in with August); with September include 0.5 of October 1; and with November 0.5 of December 1.

[1] For a further development of these functions to suit various numbers of observations in a cycle, see U. S. Coast Survey Report for 1862, Appendix No. 22.

The average representation of the mean temperature of any one month is ±2°.4, and of the mean annual temperature ±0°.7. According to the above formula the warmest day is July 15th, temperature +41°.6, and the coldest day February 16th, temperature, —28°.0. The annual mean temperature is reached on April 22d, and November 14th. On the annexed diagram the curve represents the computed annual fluctuation, and the dots the observed mean monthly temperatures.

ANNUAL FLUCTUATION OF THE TEMPERATURE OF THE AIR AT PORT FOULKE.



The monthly range, that is, the difference of the highest and lowest mean temperature of any day of the month, is greatest in November (41°), and least in July (19°).

The lowest temperature recorded (and corrected for index error) was —45°.4 on January 25th, 1861, 6 A. M., and the highest temperature recorded was +61°.0 on July 5th, 1861, 2 P. M. On the 28th of July, 1861, at Cape Isabella, in nearly the same latitude as Port Foulke, the temperature rose to +63°.0 at 10 A. M.; the vessel was then among the floe ice.[1] The extreme range of temperature experienced was therefore 108°.4 of Fahrenheit's scale; at Van Rensselaer Harbor the extreme range was 117°.4, and at Port Kennedy 104°.8.

The difference in temperature of the atmosphere at Port Foulke and Van Rensselaer Harbor, due to the cause stated in the introduction to the meteorological part,

[1] The minima thermometers (1597 and 1639) were exposed too late in the winter (March 1st) to record the lowest temperature. The maxima thermometers (1705 and 1657) recorded +67°.0 June 22d; but the two instruments differed then 8° in their indications, and their errors of graduation were not determined. No. 1657 broke July 2d, and No. 1705 was not read after July 12, 1861.

we have found to be $8\frac{1}{4}°$ on the average during the year. In March, 1861, Dr. Hayes visited the harbor, and recorded the following temperatures by thermometer No. 10.

March	18th	10 P. M.	Temperature —47°	Wind N.	Force 2
"	19th	8 A. M.	" —26 (in sun)	Calm	
"	19th	9 P. M.	" —48	Wind N. by E.	" 2
"	20th	6 A. M.	" —66.5	" N.	" 1
"	20th	9 P. M.	" —46	" N.	" 2
"	21st	6 A. M.	" —68	" N.	" 1
"	21st	Noon	" —50	" N.	" 5

Applying the correction for errors of graduation, we obtain the following comparisons of temperature.

	Port Foulke.	Van Rensselaer.	Difference (R—F).
March 18th 10 P. M.	—30°.7	—43°.4	—12°.7
" 19th 9 P. M.	—16.9	—44.4	—27.5
" 20th 6 A. M.	—16.4	—62.9	—46.5
" 20th 9 P. M.	—28.2	—42.4	—14.2
" 21st 6 A. M.	—31.2	—64.4	—33.2
" 21st Noon	—25.0	—46.4	—21.4

The average difference on these four days is 26° nearly, and the greatest difference observed, March 20, 6 A. M., is $46\frac{1}{2}°$, Van Rensselaer Harbor being so much colder. The greatest cold recorded by Dr. Kane (February 5th, 1854) was —66°.4, which exceeds the above on March 21 A. M., by 2° only; the month of March was decidedly the coldest month according to Dr. Kane's observations.

During the above four days of comparison the wind at Port Foulke was N. E. on the average; at Van Rensselaer Harbor it was N.

Diurnal Fluctuation of the Temperature of the Air.

Taking monthly means of the observed temperature at each hour of the day, and referring the readings by thermometers No. 7 and 6, in November, to thermometer No. 3 used during the second half of that month, we have the following bi-hourly mean values from which to deduce the diurnal fluctuations.

Month.	A. M.						P. M.						Thermometer.
	2h	4	6	8	10	Noon.	2	4	6	8	10	12h	
September	+20°.95	+21°.26	+21°.42	+21°.60	+21°.73	+22°.19	+22°.48	+22°.37	+21°.77	+21°.60	+21°.26	+20°.48	7
October	+5.72	+5.79	+5.57	+6.11	+6.84	+7.53	+7.77	+7.71	+7.30	+7.09	+6.18	+5.87	7
November	+2.06	+1.98	+2.92	+2.79	+2.98	+3.22	+3.26	+3.64	+3.87	+3.54	+3.42	+2.49	3
December	—9.55	—10.43	—10.91	—11.32	—10.76	—10.66	—10.56	—9.69	—10.78	—10.73	—11.36	—10.16	4
January	—23.47	—23.11	—23.63	—22.66	—22.42	—22.23	—22.84	—23.18	—23.09	—23.89	—23.21	—23.11	4
February	—23.82	—24.07	—22.95	—21.27	—21.27	—21.09	—20.11	—21.20	—21.56	—21.75	—21.63	—22.75	4
March	—22.29	—22.97	—22.39	—20.24	—19.55	—17.98	—14.64	—15.96	—18.10	—19.14	—20.48	—21.78	4
April	—13.63	—14.07	—12.50	—10.67	—10.02	—8.79	—8.00	—8.94	—9.89	—10.55	—12.39	—12.97	13
May	+18.34	+20.26	+21.43	+23.62	+24.43	+24.92	+24.60	+24.35	+24.00	+22.19	+20.61	+19.48	13
June	+30.78	+32.30	+33.25	+33.85	+35.07	+35.78	+36.59	+35.88	+35.15	+34.08	+32.57	+31.58	13
July	+39.37	+39.79	+40.21	+42.22	+43.33	+42.98	+44.78	+44.51	+43.18	+42.14	+41.69	+39.16	13

The above figures were next referred to standard thermometer No. 3, and further corrected for effect of annual change. The diurnal effect of this change was computed by the preceding formula for T, and the daily increase of temperature found as follows:—

January	—0°.28	July	—0°.10
February	—0.02	August	—0.36
March	+0.39	September	—0.39
April	+0.77	October	—0.39
May	+0.78	November	—0.40
June	+0.38	December	—0.38

for the middle of each month. Without regard to sign, one-half of these quantities will be the correction for 0^h A. M. and 12 P. M.; at noon there is, of course, no correction, and for the intermediate hours the correction is proportional to the interval from noon; the A. M. and P. M. corrections at the same hours are the same, but with signs reversed. An examination of the diurnal fluctuation in July, August, and September, at Van Rensselaer Harbor and at Port Kennedy, shows that the August value is quite well represented by a mean of the July and September values; the August value for Port Foulke has consequently been interpolated by means of the two adjacent months.

Diurnal fluctuation of the temperature.

(Corrected for errors of graduation of thermometers, and for effect of annual change.)

Month.	A. M.						P. M.					
	2^h	4	6	8	10	Noon.	2	4	6	8	10	12^h
January	—26°.67	—26°.27	—26°.81	—25°.74	—25°.47	—25°.24	—25°.86	—26°.21	—26°.09	—25°.84	—26°.16	—26°.04
February	—26.96	—27.23	—26.01	—24.21	—24.21	—24.01	—22.99	—24.14	—24.53	—24.73	—24.60	—25.78
March	—25.14	—25.90	—25.30	—23.04	—22.34	—20.66	—17.03	—18.51	—20.89	—22.04	—23.51	—24.96
April	—13.74	—14.18	—12.90	—11.38	—10.86	—9.56	—8.76	—9.86	—10.96	—11.65	—13.31	—13.87
May	+20.28	+22.18	+23.33	+25.50	+26.27	+26.72	+26.33	+26.01	+25.58	+23.67	+21.98	+20.74
June	+32.41	+33.78	+34.64	+35.18	+36.30	+36.82	+37.40	+36.85	+36.23	+35.21	+33.75	+32.80
July	+39.48	+39.80	+40.15	+41.68	+42.52	+42.26	+43.68	+43.45	+42.44	+41.66	+41.35	+39.42
(August)	+30.58	+30.92	+31.21	+32.11	+32.59	+32.73	+33.61	+33.46	+32.69	+32.23	+31.93	+30.60
September	+21.79	+22.13	+22.32	+22.54	+22.70	+23.19	+23.51	+23.43	+22.87	+22.73	+22.42	+21.68
October	+6.56	+6.66	+6.47	+7.05	+7.81	+8.53	+8.80	+8.77	+8.40	+8.22	+7.34	+7.07
November	+1.90	+1.85	+2.82	+2.73	+2.95	+3.22	+3.29	+3.70	+3.97	+3.67	+3.58	+2.69
December	—11.56	—12.84	—13.00	—13.41	—12.76	—12.63	—12.48	—11.50	—12.65	—12.57	—13.23	—11.89

If we subtract from each value the respective monthly mean, the residuals will represent the diurnal fluctuation proper, a + sign indicates higher, a — sign lower temperature than the mean of the day. The last two lines show the diurnal fluctuation for Van Rensselaer and Port Kennedy for comparison.

Month.	A. M.						P. M.					
	2h	4	6	8	10	Noon.	2	4	6	8	10	12h
January . .	—0°.64	—0°.24	—0°.78	+0°.29	+0°.56	+0°.79	+0°.17	—0°.18	—0°.06	+0°.19	—0°.13	—0°.01
February . .	—2.01	—2.28	—1.06	+0.74	+0.74	+0.94	+1.96	+0.81	+0.42	+0.22	+0.35	—0.83
March . . .	—2.70	—3.46	—2.86	—0.60	+0.10	+1.78	+5.41	+3.93	+1.55	+0.40	—1.07	—2.52
April . . .	—1.99	—2.43	—1.15	+0.37	+0.89	+2.19	+2.99	+1.89	+0.7[illegible]	+0.10	—1.56	—2.12
May . . .	—3.77	—1.87	—0.72	+1.45	+2.22	+2.67	+2.28	+1.96	+1.53	—0.38	—2.07	—3.31
June . . .	—2.70	—1.33	—0.47	+0.07	+1.19	+1.71	+2.29	+1.74	+1.11	+0.10	—1.36	—2.31
July . . .	—2.01	—1.69	—1.34	+0.19	+1.03	+0.77	+2.19	+1.96	+0.95	+0.17	—0.14	—2.07
August . .	—1.47	—1.13	—0.84	+0.06	+0.54	+0.68	+1.56	+1.41	+0.64	+0.18	—0.12	—1.45
September .	—0.81	—0.47	—0.28	—0.06	+0.10	+0.59	+0.91	+0.83	+0.27	+0.13	—0.18	—0.92
October . .	—1.08	—0.98	—1.17	—0.59	+0.17	+0.89	+1.16	+1.13	+0.76	+0.58	—0.30	—0.57
November .	—1.13	—1.18	—0.21	—0.30	—0.08	+0.19	+0.26	+0.67	+0.94	+0.64	+0.55	—0.34
December . .	+0.98	—0.30	—0.46	—0.87	—0.22	—0.09	+0.06	+1.04	—0.11	—0.03	—0.69	+0.65
Spring . . .	—2.82	—2.59	—1.58	+0.41	+1.07	+2.21	+3.56	+2.59	+1.29	+0.04	—1.57	—2.65
Summer . .	—2.06	—1.38	—0.88	+0.11	+0.92	+1.05	+2.01	+1.70	+0.90	+0.15	—0.54	—1.94
Autumn . .	—1.01	—0.88	—0.55	—0.32	+0.06	+0.56	+0.78	+0.88	+0.66	+0.45	+0.02	—0.61
Winter . .	—0.56	—0.94	—0.77	+0.05	+0.36	+0.55	+0.73	+0.56	+0.08	+0.13	—0.16	—0.06
P. F. Year .	—1.61	—1.45	—0.94	+0.06	+0.60	+1.09	+1.77	+1.43	+0.73	+0.19	—0.56	—1.32
V. R. Year .	—1.74	—1.55	—0.90	+0.17	+1.06	+1.81	+1.90	+1.40	+0.73	—0.16	—1.02	—1.64
P. K. Year .	—1.87	—1.50	—0.80	+0.25	+1.50	+2.25	+2.02	+1.34	+0.29	—0.50	—1.13	—1.87

The diurnal variation, on the average during a year, as deduced for Port Foulke and Van Rensselaer Harbor, shows a remarkable accordance for these localities; the range at the former place is a little smaller than at the latter, viz: 3°.38 and 3°.64, which is due to the equalizing effect of open water. The warmest and coldest observing hours are 2 P. M. and 2 A. M. The range at Port Kennedy is a little greater than the above, 4°.12, on account of its smaller latitude. The spring, summer, autumn, and winter ranges at Port Foulke were as follows: 6°.38, 4°.07, 1°.89, and 1°.67, respectively. In the month of December, when the sun is most depressed below the horizon, the diurnal variation becomes less regular, and approaches towards vanishing altogether.

Annual Inequality of the Diurnal Fluctuation of the Temperature.

The annual inequality is best exhibited by the monthly mean values of the diurnal range; these values for Port Foulke, Van Rensselaer Harbor, and Port Kennedy, are as follows:—

Daily range of temperature.							
	Port Foulke.	Van R.	Port Ken.		Port Foulke.	Van R.	Port Ken.
January,	1°.43	1°.55	1°.41	July,	4°.26	3°.37	6°.97
February,	4.24	3.07	1.49	August,	3.03	5.30	2.63
March,	8.87	5.66	9.55	September,	1.83	5.55	2.94
April,	5.42	9.09	7.42	October,	2.24	1.67	2.18
May,	6.44	7.34	7.94	November,	1.55	1.00	2.17
June,	4.99	5.10	9.60	December,	0.18	1.65	0.84

This table exhibits more strikingly the difference in the climate of the two localities which at Port Foulke is the more equable. To obtain the November and December range, which is marked by the accidental irregularities of the temperature, an average value near the hours of maxima and minima has been used.

Annual Inequality in the Diurnal Amplitude of the Temperature at Port Foulke.

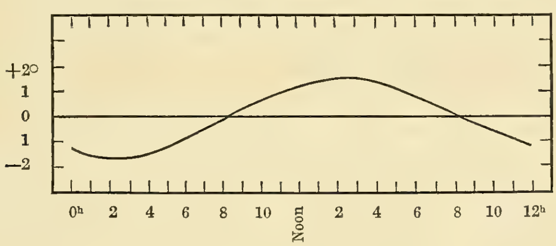
The daily range is greatest in spring, in March it attains its maximum value, then falling a little and rising again in May, it diminishes till December, when it reaches its minimum value. The great rise in spring is due to the immediate effect of the sun *before* it has power enough to melt a sufficient quantity of ice to check it. The small depression of the curve, in the spring and early summer, and shown by the three localities discussed, is most likely due to the increasing vapor. A more full material for discussion would probably bring out a small increase in the range late in summer or early in autumn, at a time when the freezing process again comes into powerful action. Of such an increase we have at present only a trace.

In the following expression of the diurnal fluctuation during the whole year, the angle θ counts from midnight at the rate of 15° an hour. To this expression those for the other localities were added for comparison.

Port Foulke, $t = + 1^\circ.57 \; sin\,(\theta + 235^\circ\, 8') + 0^\circ.02 \; sin\,(2\theta + 195^\circ) + 0^\circ.11 \; sin\,(3\theta + 148^\circ)$
Van Rensselaer, $t = + \; 1.85 \; sin\,(\theta + 244\; 55\,) + \; 0.08 \; sin\,(2\theta + \;\; 97\;\,) + \; 0.03 \; sin\,(3\theta + 308\;\,)$
Port Kennedy, $t = + \; 2.02 \; sin\,(\theta + 252\; 57\,) + \; 0.25 \; sin\,(2\theta + 117\;\,) + \; 0.09 \; sin\,(3\theta + 251\;\,)$

The probable error of any single representation, for Port Foulke, is $\pm 0^\circ.08$.

Diurnal Fluctuation of the Temperature. Mean Annual Value.



According to the formula the temperature rises till $2\frac{1}{2}$ P. M., when it attains its greatest value; it reaches its lowest value at $2\frac{1}{2}$ A. M., and its average value about 8 A. M. and 8 P. M.

Supposed Dependence of the Winter Temperature on the Lunar Phases.

The supposed lower temperature about the time of full moon when compared with that about new moon, during mid-winter, noticed by some Arctic explorers, and which received confirmation from observations during two winters at Van Rensselaer Harbor, and partial confirmation from observations during two winters in Baffin Bay and at Port Kennedy, is not sustained by the observations at Port Foulke, as may be seen from the following collection of mean daily temperatures, each the mean of five days, two of which precede and two of which follow the lunar phase; to allow for the annual change of temperature the *alternate* means are set out. These alternate mean temperatures, and the observed temperatures, are then compared by subtracting the temperature at the new moon from that at full moon; a negative sign indicates greater cold at full than at new moon.

	Observed temperature.	Alternate means.	Difference ○ — ◍
○ October 29, 1860	—0°.7		
◍ November 13, "	+4.5	+8°.4	+3°.9
○ November 28, "	+17.5	—7.2	+24.7
◍ December 12, "	—19.0	—0.2	+18.8
○ December 28, "	—18.0	—18.4	+0.4
◍ January 11, 1861	—17.8	—23.2	—5.4
○ January 26, "	—28.5	—21.7	—6.8
◍ February 9, "	—25.7	—24.8	+0.9
○ February 25, "	—21.2	—21.6	+0.4
◍ March 11, "	—17.6	—21.2	—3.6
○ March 26, "	—21.3	—17.9	—3.4
◍ April 10, "	—18.2	—13.8	+4.4
○ April 24, "	—6.2	+5.1	—11.3
◍ May 9, "	+28.4		

If we take the differences from the middle of December to the end of March, the temperature would appear 2°.5 colder at full than at new moon; the high temperature about November 28, and the low temperature about December 12, however, are such strong contradictions to the supposed law, as to deprive the results collected by the expedition of any decisive value. About November 28, the prevailing wind was S. W., charged with heat and vapor from the open water spaces of North Baffin Bay; about December 12, the prevailing wind was N. E. Neither Port Foulke nor Port Kennedy are favorably situated for the experimental study of the phenomenon.

Relation of the Atmospheric Temperature to the Direction of the Wind.

The method pursued to ascertain the elevating or the depressing influence of the various winds on the temperature of the air, is as follows: The average daily temperature for each day of the year was computed by means of the expression for T, this was readily done by the use of the formula for a number of equi-distant intervals, and by the application of the principle of interpolation "into the middle" (which secures the proper value to third differences inclusive). The previously used correction for graduation of thermometers was next applied *with sign reversed* so as

to give the daily normal reading for comparison with the actual reading on that day as observed. For the hours 8 A. M. and 8 P. M. this comparison is strict since the diurnal fluctuation at these hours is nil; but for the comparisons of 2 A. M. and 2 P. M. a new set of tables of normal temperatures were constructed by applying the correction for maximum diurnal fluctuation at these hours to our first table of normals. We thus have four comparisons, at equal intervals, four observations each day; these differences of temperature were tabulated and inserted in the proper column for the direction of the wind then observed. There were nine such columns, one for each of the eight principal directions and one for calms. The mean difference for each wind, for a period extending over a season, very nearly indicates the elevating or depressing influence of each wind. A + sign indicates warmer, a — sign colder temperature than the normal. An extension of this investigation to twelve hours a day would only add to the labor without materially affecting the result. By the process adopted the influence of the wind will be found independent of the annual and diurnal fluctuation of temperature, and any possible tendency of the wind to blow from a certain direction at the same time each day can be taken into account.

The results for the hours 2 A. M., 8 A. M., 2 P. M., and 8 P. M., do not materially differ; thus for the N. E. wind we find at these hours —1°.9, —2°.1, —1°.7, and —1°.8 respectively, and for the warmer S. W. wind at the same hours, +2°.6, +0°.5, +1°.0, and +0°.4.

As there are but few entries of winds from the north, east, south, west, and northwest, the results were contracted in two means, one for the winter half of the year (October to March inclusive), the other for the summer half (April to September inclusive). The blanks in the table indicate too few observations to give any reliable result; numbers between brackets are of little value.

Elevating (+) or depressing (—) effect of the winds on the temperature of the air.

	N.	N. E.	E.	S. E.	S.	S. W.	W.	N. W.	Calm.
Winter half year .	+2°.5	—1°.6	- - - -	+3°.5	- - - - -	+5°.1	- - - - -	- - - - -	—2°.2
Summer " .	—0.2	—2.2	- - - -	—0.3	- - - - -	—1.1	- - - - -	- - - - -	+3.0
Year	+1.3	—1.9	—1°.1	+2.4	(+8°.7)	+1.2	(+9°.8)	(—0°.3)	—0.3
Number of entries	36	637	7	49	7	225	11	7	374

The northeast and east winds are cold winds, the southeast, south, southwest (and probably west also) are warm winds; calms depress the temperature. The northeast wind is cold all the year round, and the southwest is warm, particularly in the winter; during winter calms are accompanied by a lower temperature; during summer by a high temperature, in opposition to the winds. The distribution of the winds is very irregular; the prevailing wind, northeast, blows longer than all the other winds together, in which time that of the calms may also be included.

If we take for the effect of south and west winds the mean of the effect of the adjacent winds, and subtract 0°.5 from all numbers, we find the values given below.

True direction of wind.	Port Foulke $\phi = 78° 18'$ $\lambda = 73\ 00$	Van Rensselaer $\phi = 78° 37'$ $\lambda = 70\ 53$
N.	$+0°.8$	$-1°.4$
N. E.	-2.4	0.0
E.	-1.6	-0.1
S. E.	$+1.9$	$+0.9$
S.	$+1.3$	$+0.6$
S. W.	$+0.7$	$+0.4$
W.	-0.1	$+0.1$
N. W.	-0.8	-1.4

We have, therefore, for comparison the following expressions[1]:—

Port Foulke . . . . $\tau = + 1°.2\ sin\ (\theta + 249°) + 1°.2\ sin\ (2\theta + 126°)$
Van Rensselaer Harbor . . $\tau = + 1.0\ sin\ (\theta + 286\ ) + 0.3\ sin\ (2\theta + 335\ )$
Baffin Bay ($\phi = 72°.5$, $\lambda = 65°.8$) $\tau = + 1.5\ sin\ (\theta + 338\ ) + 0.8\ sin\ (2\theta + 173\ )$
Port Kennedy . . . . $\tau = + 0.9\ sin\ (\theta + 320\ ) + 0.4\ sin\ (2\theta + 26\ )$

The angle θ counts from the north (or belongs to a true north wind) in the direction east, south, etc.

Effect of a fall of Snow (or Rain) on the Temperature.

The effect produced by the change of latent into sensible heat, during the precipitation of snow (or rain), is far greater than the effect of the variation in the direction of the winds.

At Port Foulke it snowed on 94 days in *eleven* months; the total number of hours of precipitation during this time was 656. It rained on 15 days in June, and July, and November; total number of hours 79. This is considerably more snow and rain than at Van Rensselaer Harbor, where Dr. Kane noted snow during 680 hours, and rain during 60 hours, in *seventeen* months. The snowy and rainy days are distributed over the year as follows:—

In September	6	In March	8
" October	10	" April	8
" November	12	" May	9
" December	4	" June	16
" January	8	" July	13
" February	7		

The *elevating* effect on the *winter* temperature is as decidedly brought out as the *depressing* effect on the *summer* temperature; the former, however, is six times as great as the latter. If we compare the observed temperature (at the hours 2 A. M. and P. M., and 8 A. M. and P. M.) with the corresponding normal temperature during each fall of snow (or rain) according to the method pursued in the preceding investigation, we find from 85 cases in the winter half of the year (October to March inclusive) the elevating effect on the average $= 8°.6$, and from 86 cases in the summer half of the year (April to September) the depressing effect on the average $1°.5$; during the whole period, therefore (in 11 months), the average effect was $+3.°5$; at Van Rensselaer Harbor the corresponding quantity was $+7°.7$.

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[1] See p. 30 of reduction of Sir F. L. McClintock's Meteorological Observations.

The maximum elevating effect in winter amounted to 36° (November 28, 1860), and the maximum depressing effect in summer to 9° (July 25, 1861).

This annual variation is well shown in the table given for Van Rensselaer Harbor, where the maximum effect was on the *average in January* +19°, and the opposite effect on the *average in June* —1°.3, and is, indeed, a most marked feature at either locality.

Effect of Clear and Cloudy Weather on the Temperature.

To ascertain the effect upon the temperature of a serene and cloudy atmosphere, the temperature observed on clear days (or at least three-quarters clear), and on cloudy days (or at least three-quarters cloudy), was compared with the normal temperature of the day; a + difference indicates warmer, a — difference a colder day than the normal; for this investigation the year was again divided into two seasons.

The *clear* days preponderate in the *winter* season, the *cloudy* days in the summer season; thus in

December		18		4
January	there are	19	clear days, and but	1	cloudy days, and in June and
February		17		1

July there are 4 and 8 clear days, and 16 and 15 cloudy days.

In winter (October to March inclusive) on the average from 82 *clear* days the temperature was *lower* 3°.5 than the normal, and in summer (April to September inclusive) on the average from 41 *clear* days the temperature was *higher* 0°.8 than the normal; a clear atmosphere consequently produces opposite effects in the summer and winter seasons.

In winter on the average from 31 *cloudy* days the temperature was *higher* 7°.0, and in summer on the average from 48 days it was *lower* 2°.1 than the normal value.

The explanation of these results is obvious: In winter, under a clear sky, radiation soon lowers the temperature, whereas a clear sky in summer by permitting greater insolation, will increase the temperature. In cloudy weather in winter, radiation is stopped, and with an atmosphere nearly or quite saturated with moisture the temperature must rise; in summer insolation is prevented, and consequently the temperature will remain lower than its normal value.

Observations of the Direct Heating Power of the Sun.

For the measure of the direct heating effect of the sun, two black bulb thermometers were exposed on the floe near the ship.

B. B. thermometers, Nos. 1648 and 1704.
Temperature in sun, at Port Foulke.

	1648.	1704.	
1861. Feb'y 26th	—17°.5	—15°.5	at 2½ P. M.
" 27th	—18.0	—17.5	" "
" 28th	—15.5	—13.5	" "
March 4th	—16		at 2½ P. M., —18° at 3 P. M.
" 6th	—22	—21	at 2 P. M., —23°.5 and —21° at 3 P. M.
" 7th	—19	—18	at 3 P. M.
" 8th	—11.5	—10	at 3 P. M., —12° and —10° at 4 P. M.
" 9th	—7	—5	at 3 P. M., —9.5 and —8° at 4 P. M.
" 11th	—9	—4	"
" 12th	—12	—11	at 3 P. M., —12.5 and —12.5 at 5 P. M.
" 13th	—16	—14	at 5 P. M.
" 14th	—22	—20.5	at 3 P. M., —22 and —20.5 at 5 P. M
" 15th	—22	—18	at 5 P. M.
" 16th		—2	at 3 P. M., and —3° at 5 P. M.
" 17th		+1	"
" 22d		+1	at 3 P. M., and —7.5 at 5 P. M.
" 23d		+1	at 1 P. M., +3° at 3 P. M., +2° at 5 P. M.
" 24th		+1	at 1 P. M., —4 at 3 P. M., —8 at 5 P. M.
" 26th		—9.5	at 1 P. M., —12.5 at 3 P. M., —8 at 5 P. M.
" 29th		+6	at 1 P. M., +6 at 3 P. M., —1.5 at 5 P. M.
" 30th		—5	at 1 P. M., —2.5 at 3 P. M.
" 31st		+14	at 1 P. M., +4 at 3 P. M.
April 1st		+8	at 1 P. M., +8 at 3 P. M.
" 3d		—10	at 1 P. M., —5 at 3 P. M., 0° at 5 P. M.
" 4th		+21	at 3 P. M., —5 at 7 P. M.
" 8th		—11	at 1 P. M., —13 at 3 P. M.
" 9th		—12	at 1 P. M., —5 at 5 P. M.
" 12th		+14	at 5 P. M.
" 13th		—7	at 3 P. M.
" 14th		—6	at 1 P. M., —9 at 3 P. M.
" 15th		+1	at 3 P. M.
" 16th		+3	at 11 A. M.
" 17th		—5	at 11 A. M.
" 18th		+13	at 11 A. M., +18 at 1 P. M. Snow melting on side of ship.
" 20th		+10	at 11 A. M., +23 at 1 P. M. +19 at 3 P. M. +13 at 5 P. M.
" 22d		+17	at 1 P. M., +13 at 3 P. M., +9 at 5 P. M.
" 23d		+2	at 9 A. M., +21 at 11 A. M., +18 at 1 P. M., +5 at 3 P. M.
" 26th		+12	at 9 A. M., +28 " +15 at 5 "
" 27th		+6.5	at 1 P. M., +5 at 3 P. M., +4 at 5 P. M., 0 at 7 P. M.
" 28th		+5	at 11 A. M., +8 at 1 P. M., +5.5 at 3 P. M.
" 29th		+10	at 3 P. M.
" 30th		+13	at 11 A. M., +17 at 1 P. M., +18 at 3 P. M.
May 1st		+15	at 9 A.M., 11 A.M., 1 P.M., 3 P.M., 5 P.M., +13.5 at 7 P.M.
" 2d		+8	at 11 A. M., 5 P. M., +13 at 7 P. M.
" 3d		+25	at 11 A. M., +24 at 1 P. M., +22 at 3 P. M.
" 5th		+20	at 9 A. M., +29 at 11 A. M., +24 at 1 P. M., 3 P. M. +25 at 5 P. M.
" 6th		+35	at 1 P. M., 3 P. M., +35.5 at 5 P. M., +31 at 7 P. M.
" 7th		+30	at 11 A. M., +34 at 1 P. M., +32 at 3 P. M.

The above observations were made in *clear* weather.

Observations of Temperature made by Dr. Hayes on his Journey to the Northward, in April and May, 1861.

On this journey Dr. Hayes reached his extreme northern latitude, at Cape Lieber, of 81° 37′, in longitude 69¼° west of Greenwich, on the 18th of May. The following temperatures were recorded by him:—

May	5	Scouse Camp,	$\phi = 79° 29'$	at	6 A. M.	Temp.	—8°	
"	5	" "	$\lambda = 72$ 53	"	1 P. M.	"	—2	In sun +28°
"	5	" "		"	6 "	"	0	" " +27
"	6	" "		"	7 "	"	+7	" " +19½
"	7	No Hut Camp,		"	¼ "	"	- - -	" " +47
"	7	" "		"	4 "	"	+11½	" " +44
"	8	Pipe Camp,		"	7 A. M.	"	+14	
"	8	" "		"	4 P. M.	"	+24	
"	10	Near Cape Hawks,			noon		- - - -	+36° in sun
"	10	" "		"	6½ P. M.		- - - -	+50 "
"	11	Cape Hawks Camp,	$\phi = 79° 44'$ $\lambda = 73$ 06	"	3 A. M.	"	+12	
"	12	Near Cape Hawks,		"	0 "	"	+5	+18 "
"	12	Near Cape L. Napoleon,		"	6 "		- - - -	+36½ "
"	12	" " "		"	4½ P. M.	"	+21	
"	13	Foggy Comp.	$\phi = 79° 56'$	"	4 A. M.	"	+26	
"	13	" "	$\lambda = 71$ 28	"	6½ P. M.	"	+18	
"	13	Near Frazer Camp,		"	11¼ "	"	+9	
"	14	Frazer Camp,	$\phi = 80° 06'$	"	6 A. M.	"	+26	
"	14	" "		"	2½ P. M.		- - - -	+58 in sun. Light south wind
"	14	" "		"	3 "	"	+28	
"	14	" "		"	6 "	"	+20	
"	15	Tired dog's Camp,		"	2½ A. M.	"	+21	+30°
"	15	" "		"	4½ P. M.	"	+23	
"	16	Jensen's Camp,[1]	$\phi = 80° 48'$	"	0 A. M.	"	+20	Fog
"	16	" "		"	4 "	"	+19	"
"	16	" "		"	8 "	"	+22	In sun 38°
"	16	" "			noon	"	+28	" " 48
"	16	" "		"	4 P. M.	"	+24	" " 42
"	16	" "		"	8 "	"	+26	" " 49
"	17	" "		"	0 A. M.	"	+21	Fog
"	17	" "		"	4 "	"	+26	"
"	17	" "		"	8 "	"	+18	In sun 36°
"	17	" "			noon	"	+32	" " 40
"	17	" "		"	4 P. M.	"	+20	Fog
"	17	" "		"	8 "	"	+23	Snow
"	18	" "		"	0 A. M.	"	+14	Wind and snow throughout the day
"	18	" "		"	4 "	"	+16	
"	18	" "		"	8 "	"	+18	
"	18	" "			noon	"	+22	
"	18	" "		"	4 P. M.	"	+16	
"	18	" "		"	8 "	"	+14	
"	19	" "		"	0 A. M.	"	+12	Wind and snow
"	19	" "		"	4 "	"	+14	
"	19	" "		"	8 "	"	+14	
"	19	" "			noon	"	+16	
"	20	Camp Leidy,	$\phi = 79° 58'$	"	2½ A. M.	"	+8	Weather thick, strong N. W. wind; light snow
"	20	" "		"	4½ P. M.	"	+22	Light S. W. wind, cloudy; light snow

[1] Recorded by G. F. Knorr, during Dr. Hayes' absence.

May 21	Near Deep Snow Camp, $\phi = 79° 55'$	at 3 A. M.	Temp. +22	Cloudy; snowing.
" 21	" "	" 7 P. M.	" +8	
" 21	" "	" 10 "	" —4	
" 22	Camp Hawks, $\phi = 79° 44'$	" 8 A. M.	" +15	Light N. W. wind; cloudy
" 22	" " $\lambda = 73$ 06	" 6 P. M.	" +13	+19° in sun
" 22	" "	" $8\frac{1}{3}$ "	0	
" 23	Near Smallberg Camp, $\phi = 79° 33'$	" 7 A. M.	" +20	+32 "
" 23	" " " $\lambda = 72$ 53	" $7\frac{1}{2}$ P. M.	" +13	+22 "
" 24	Near Broken Sledge Camp,	" 7 A. M.	" +14	+32 "
" 24	" " "	" 6 P. M.	" +18	
" 25	Near Potato Camp, $\phi = 79° 04'$	" 1 A. M.	" +19	
" 25	and near $\lambda = 72$ 30	" $7\frac{1}{2}$ "	" +18	+38 "
" 26	Camp Separation, $\phi = 78$ 53	" 0 "	" +4	
" 26	" " $\lambda = 72$ 08	" $6\frac{1}{3}$ "	" +17	+32 "
" 26	" "	" 6 P. M.	" +16	+30 "

To complete the record of the weather during the above period, the following note is added:—

1861. April 21. Near Cairn Point. Storm stayed
April 24. " " "

The following table contains the mean daily temperature in the shade derived from the above by application of the known average value of the diurnal variation taken from the table p. 39 of my discussion of the temperature observations at Van Rensselaer Harbor, and the preceding table of the diurnal fluctuation at Port Foulke, after changing sign in the latter.

Date. 1861. May.	Locality and latitude.		Mean temperature of day.	Port Foulke, mean temp. of day.
5	Scouse Camp,	$\phi = 79° 29'$	—4°.5	+14°.6
6	" "		+6.2	+23.2
7	No Hut Camp,		+8.9	+22.5
8	Pipe Camp,		+17.6	+27.9
9	" "		- - - - -	+29.3
10	Near Camp Hawks,		- - - - -	+32.0
11	Cape Hawks Camp,	$\phi = 79° 44'$	+15.2	+30.0
12	Near Cape Hawks,		+13.5	+33.6
13	Foggy Camp,	$\phi = 79$ 56	+19.0	+35.8
14	Frazer Camp,	$\phi = 80$ 06	+23.4	+33.5
15	Tired dog's Camp,		+22.6	+33.2
16	Jensen's Camp,	$\phi = 80$ 48	+23.1	+32.0
17	" "		+23.2	+27.3
18	" "		+16.6	+20.4
19	" "		+14.5	+16.9
20	Camp Leidy,	$\phi = 79° 58'$	+15.2	+16.8
21	Near Deep Snow Camp,	$\phi = 79$ 55	+10.1	+20.9
22	Camp Hawks,	$\phi = 79$ 44	+8.5	+22.2
23	Near Smallberg Camp,	$\phi = 79$ 33	+16.2	+20.9
24	Near Broken Sledge Camp,		+15.0	+24.1
25	Near Camp Separation,	$\phi = 78$ 53	+20.0	+24.9
26	" " "		+13.0	+30.6

On the average, therefore, it was 10°.7 colder on the route across Smith Sound, and up the west coast of Kennedy Channel, that at Port Foulke. At Jensen's Camp, where we have observations on four days, it was on the average 4°.8 colder than at Port Foulke; the difference of latitude of these places is 2° 30′.

ATMOSPHERIC PRESSURE.

THE atmospheric pressure was observed by means of a mercurial barometer suspended on board the schooner; its index error, if any, is not known. The readings are given in English inches, and those of the attached thermometer in degrees of Fahrenheit.

The observations here recorded commence with September 1, 1860, and extend to August 1, 1861; the record is nearly complete for the hours 8, 10, noon, 2, 4, 6, 8, 10, P. M., but for midnight and the morning hours 2, 4, 6, it is defective, and in April, May, and June, observations at these hours are altogether wanting.

For the reduction of the readings to the temperature of freezing water, Table XVII, C, of Guyot's Meteorological and Physical Tables (Smithsonian Miscellaneous Collection) was employed.

The approximate reduction of the readings of the barometer to the level of the sea is +0.006 inches.

25 November, 1865.

Readings of the barometer and attached thermometer near and at Port Foulke, Smith Strait.
September, 1860.

Day of the month.	2^h		4		6		8		10		Noon	
[1]1	---	---	---	---	---	---	$29^{in}.70$	67°	$29^{in}.75$	52°	$29^{in}.75$	55°
2	---	---	---	---	---	---	.75	58	.70	75	.80	80
3	---	---	---	---	---	---	.70	65	.70	65	.70	62
4	---	---	---	---	---	---	.70	75	.70	75	.60	60
5	---	---	---	---	---	---	.65	61	.70	76	.70	76
6	---	---	---	---	---	---	.90	76	.90	78	.90	70
7	$29^{in}.95$	62°	---	---	---	---	---	---	30.10	66	30.10	70
8	---	---	---	---	---	---	30.05	64	.05	63	.00	64
9	---	---	---	---	---	---	29.95	63	29.90	62	29.90	60
10	---	---	---	---	---	---	.55	61	.50	68	.50	60
11	---	---	---	---	---	---	.50	68	.50	68	.50	74
12	.55	49	$29^{in}.56$	47°	---	---	.65	67	.65	70	.60	61
13	.76	59	.75	70	$29^{in}.76$	66°	.78	60	.83	61	.88	66.5
14	.98	56	.85	38	.85	34	---	---	.80	72	.75	62.5
15	.78	59	.75	77	.75	63	.85	62	.80	73	.83	83
16	.90	58	.90	72	.90	60	.88	72	.85	66	---	---
17	.75	61	.75	68	.75	72	.78	64	.75	72	.75	68
18	.82	69	.82	68	.85	41	.84	66	.81	68	.83	63
19	.92	70	.92	63	.92	73	.90	70	.92	75	.90	63
20	.87	40	.87	47	.92	74	.98	74	---	---	.90	59
21	30.01	75	30.10	75	30.15	70	30.12	75	30.15	67	30.18	62
22	.25	75	.20	70	---	---	.20	67	---	---	.10	64
23	29.60	48	29.58	63	---	---	29.50	66	29.35	60	---	---
24	.55	67	.55	65	---	---	.60	67	.60	75	29.55	68
25	.59	52	.55	59	29.52	53	.70	78	---	---	---	---
26	---	---	.63	47	72	46	.80	70	.75	70	.77	76
27	---	---	---	---	.82	63	.80	65	.75	21	---	---
28	.75	72	.80	61	.70	70	.68	58	---	---	.53	27
29	.57	64	.65	56	.55	55	---	---	---	---	.60	18
30	---	---	.63	17	.65	12	.70	23	.70	25	.70	21
Means of 30 values							29.790	64.0	29.773	63.3	29.768	60.2

[1] Barometer below deck.

Readings of the barometer and attached thermometer near and at Port Foulke, Smith Strait. September, 1860.

Day of the month.	2^h		4		6		8		10		Midnight	
1	$29^{in}.75$	57°	$29^{in}.75$	57°	$29^{in}.75$	61°	$29^{in}.75$	63°	$29^{in}.75$	68°	---	--
2	.86	78	---	---	---	---	---	---	---	---	---	--
3	.70	65	.70	63	.70	65	.70	63	.75	66	---	--
4	.55	62	.55	62	.55	75	.55	75	.55	73	$29^{in}.55$	73°
5	---	---	---	---	---	---	.80	73.5	.80	73	---	--
6	.85	56	.85	65	.90	66	.95	66	.95	66	.95	63
7	30.10	67	30.05	53	30.05	60	30.05	62	30.05	47	---	--
8	.00	71	.03	71	.03	68	.03	72	.00	68	---	--
9	29.85	62	29.80	58	29.80	67	29.75	66	---	---	---	--
10	.50	70	.50	67	.50	61	.50	66	29.50	65	---	--
11	.50	70	.50	73	.53	63	.55	61	.56	55	.55	55
12	.65	61	.66	60	.67	58	.67	60	.70	65	.75	60
13	.90	66	.92	58	.93	52	.92	60	.92	72	.93	73
14	.73	72	---	---	.70	65	.70	68	.73	66	.76	66
15	.80	68	.80	68	.83	74	.77	69	.88	74	.84	74
16	.80	68	.80	70	.80	72	.78	59	.80	50	.78	65
17	.80	71	.83	65	.80	50	---	---	.82	78	.85	70
18	.83	62	.83	70	.82	70	.90	69	.92	65	.92	65
19	.90	68	.90	66	.94	71	.94	78	.94	65	.88	53
20	.95	70	.95	56	.99	72	.90	70	.99	70	30.01	65
21	30.18	62	30.20	58	30.20	68	---	---	---	---	.20	74
22	.00	64	29.80	52	29.90	51	.88	56	.80	71	29.72	61
23	29.48	50	.55	61	.35	56	.50	49	.52	47	.52	77
24	.60	70	.60	62	.55	68	.55	68	.55	73	.55	58
25	.75	63	.75	72	---	---	.75	65	.65	79	.67	62
26	.78	75	.90	79	.80	33	.81	32	.95	70	.88	62
27	.73	24	.82	73	.82	87	---	---	---	---	.66	64
28	.52	29	---	---	.60	66	.58	72	.55	71	.61	70
29	.60	18[1]	.68	20	.68	19	.70	13	.60	13.5	.75	21
30	.70	25	.70	22	.70	19	.70	21	.65	20	.61	20
Means of 30 values	29.770	60.6	29.777	61.5	29.775	61.7	29.776	62.1	29.779	63.7		

[1] Barometer placed on deck.

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait.
October, 1860.

Day of the month.	2h		4		6		8		10		Noon	
1	29in.55	18°	---	---	29in.55	20°	29in.55	20°	29in.55	21°.5	29in.55	25°
2	.66	30	29in.72	28°	.80	30	.78	32	.85	27	.80	42
3	---	---	.82	35	.80	32	.85	28	.81	24	.77	23
4	.88	35	---	---	.81	33.5	.90	35	.95	40	.98	48
5	.98	44	30.04	43	---	---	30.00	48	30.00	46	.95	40
6	.87	45	29.88	44	.85	42	29.80	46	29.80	48	.80	48
7	.73	45	---	---	.90	43	.90	47	.90	49	.90	51
8	30.00	42	30.00	42	30.00	41	30.05	42	30.05	44	30.05	43
9	---	---	---	---	---	---	.15	47	.15	53	.15	50
10	---	---	---	---	---	---	.20	48	.20	53	.20	20
11	---	---	---	---	---	---	29.84	15	29.85	50	29.81	22
12	29.700	41	29.700	39	---	---	.480	48	.374	19.5	.450	53
13	---	---	---	---	---	---	.552	38	.552	43	.556	48
14	---	---	---	---	---	---	.254	23	.254	26	.250	28
15	---	---	---	---	---	---	.275	25	.275	28	.270	24
16	---	---	---	---	---	---	28.916	23	28.917	25	28.940	25
17	---	---	---	---	---	---	29.456	25	---	---	---	---
18	---	---	---	---	---	---	.424	28	29.420	28	29.426	28
19	---	---	---	---	---	---	.666	20	.670	24	.732	28
20	---	---	---	---	---	---	.568	18	---	---	---	---
21	---	---	---	---	---	---	.430	28	.550	27	.550	27
22	---	---	---	---	---	---	.536	35	.530	36	.516	36
23	---	---	---	---	---	---	.332	28	---	---	---	---
24	---	---	---	---	---	---	.432	31	.444	32	.440	31
25	---	---	---	---	---	---	.378	28	.375	28	.356	27
26	---	---	---	---	---	---	.428	31	---	---	---	---
27	---	---	---	---	---	---	.492	32	---	---	---	---
28	---	---	---	---	---	---	.442	25	.476	27	.542	28
29	---	---	---	---	---	---	.728	20	.754	28	.778	28
30	---	---	---	---	---	---	.778	24	.776	24	.788	31
31	---	---	---	---	---	---	.778	35	.770	35	.773	37
Mean of 31 values							29.624	31.4	29.628	33 0	29.631	33.1

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait. October, 1860.

Day of the month.	2^{h}		4		6		8		10		Midnight.	
1	29^{in}.60	32°	29^{in}.60	29°	29^{in}.65	28°	29^{in}.65	23°	29^{in}.70	24°.5	29^{in}.69	30°
2	.85	46	.85	31	.84	26	.85	27	---	---	.85	27
3	.77	27	.85	32	.85	40	.85	36	.88	40	.98	38
4	.98	46	.98	47	.98	46	30.00	48	30.08	49	---	---
5	.95	42	.95	41	.90	54	29.90	53	29.90	52	.84	40
6	.80	40	.80	48	.80	50	.82	52	.85	53	.75	47
7	.93	48	.95	45	.95	43	.98	43	30.00	44	---	---
8	30.10	48	30.10	48	30.15	52	30.15	51	.18	50	30.20	48
9	.10	47	.05	47	.05	45	.05	45	.07	30	---	---
10	.15	20	.15	20	.10	23	.10	25	.05	25	.01	44
11	29.80	28	29.80	53	29.79	24	29.80	52	29.75	46	29.64	42
12	.430	50	.450	52	.453	52	.462	52	.462	52	---	---
13	.552	46	.552	46	.551	43	.550	43	---	---	---	---
14	.243	32	.220	32	.157	32	.157	31	.154	28	---	---
15	.268	26	.158	24	.053	24	.054	23	.054	23	---	---
16	28.940	25	28.943	23	28.953	23	.106	25	.110	25	---	---
17	---	---	---	---	29.450	25	.450	25	.391	25	---	---
18	29.450	25	29.450	25	.472	25	.470	23	.560	23	---	---
19	.676	23	.714	24	.720	24	.728	24	.716	24	---	---
20	.436	18	.434	21	.430	20	.430	21	.430	24	---	---
21	.563	28	.564	27	.564	27	---	---	---	---	---	---
22	.530	34	.550	34	.562	32	.532	32	.460	30	---	---
23	.350	29	.482	27	.450	27	.438	26	.408	25	---	---
24	.440	31	.438	30	.435	31	.435	28	.435	25	---	---
25	.358	29	.358	31	.400	31	.417	27	.418	27	---	---
26	---	---	.408	32	.420	32	.428	31	.428	31	---	---
27	.476	32	.454	32	.450	32	.442	30	.400	26	---	---
28	.576	28	.576	30	.580	30	.620	28	.620	24	---	---
29	.816	28	.816	27	.816	23	.852	23	.852	22.5	---	---
30	.788	34	.754	36	.754	36	.750	36	.747	35	---	---
31	.778	37	.784	36	.790	34	.746	34	.746	33	---	---
Mean of 31 values	29.631	33.4	29.633	34.0	29.630	33.4	29.638	33.5	29.639	32.6		

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait.
November, 1860.

Day of the month.	2h		4		6		8		10		Noon	
1	---	---	---	---	---	---	29in.678	29°	29in.652	28°	29in.600	28°
2	---	---	---	---	---	---	.688	23	.752	23	.800	23
3	---	---	---	---	---	---	30.036	21	30.036	23	30.036	23
4	---	---	---	---	---	---	.112	23	.120	23	.120	23
5	---	---	---	---	---	---	.206	28	.208	28	.208	28
6	---	---	---	---	---	---	.108	23	.108	23	.086	23
7	---	---	---	---	---	---	29.772	9	29.772	15	29.772	16
8	---	---	---	---	---	---	30.100	25	30.150	30	30.186	35
9	---	---	---	---	---	---	29.952	36	29.904	37	29.908	38
10	---	---	---	---	---	---	30.478	36	30.550	35	30.572	35
11	---	---	---	---	---	---	.728	34	.726	36	.718	40
12	---	---	---	---	---	---	.522	38	.500	35	.478	34
13	---	---	---	---	---	---	.456	35	.448	35	.312	36
14	---	---	---	---	---	---	.152	25	.116	25	.090	25
15	---	---	---	---	---	---	29.972	20	29.956	21	29.932	22
16	---	---	---	---	---	---	.772	25	.742	26	.700	21
17	---	---	---	---	---	---	.628	25	.636	25	.700	25
18	---	---	---	---	---	---	.820	25	.844	25	.852	25
19	---	---	---	---	---	---	.812	24	.810	25	.800	25
20	---	---	---	---	---	---	.830	21	.852	21	.900	22
21	---	---	---	---	---	---	30.074	30	30.046	27	30.092	32
22	---	---	---	---	---	---	29.950	25	29.946	25	29.876	25
23	---	---	---	---	---	---	.926	28	.984	30	30.006	30
24	---	---	---	---	---	---	.972	25	30.000	25	.078	25
25	---	---	---	---	---	---	30.700	35	.724	35	.746	36
26	---	---	---	---	---	---	.632	28	.586	30	.484	29
27	30in.146	23°	30in.066	25°	30in.084	26°	.074	33	.104	30.5	.132	33
28	---	---	---	---	---	---	.202	47	.206	47	.206	47
29	---	---	---	---	---	---	.308	45	.246	45	.186	45
30	---	---	---	---	---	---	29.930	30.5	29.924	43	29.912	51
Mean,							30.086	28.4	30.088	29.2	30.083	30.0

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait. November, 1860.

Day of the month.	2h		4		6		8		10		Midnight.	
1	29in.576	25°	29in.582	23°	29in.610	23°	29in.628	20°	29in.636	20°	- - -	- - -
2	.818	25	.876	24	.950	28	.962	27	.86	25	- - -	- - -
3	30.036	23	30.038	23	30.046	23	30.056	23	30.046	23	- - -	- - -
4	.124	23	.124	25	.124	28	.106	28	.106	28	- - -	- - -
5	.232	28	.238	28	.242	25	.258	23	.258	23	- - -	- - -
6	.058	20	.032	20	.000	18	.000	18	29.984	18	- - -	- - -
7	29.772	16	29.772	14	29.772	12	29.750	10	.762	12	- - -	- - -
8	30.188	35	30.186	35	30.158	35	30.064	35	30.000	35	- - -	- - -
9	29.950	38	29.956	38	.100	39	.154	39	.196	39	- - -	- - -
10	30.638	35	30.652	35	.692	35	.698	35	.750	34	- - -	- - -
11	.722	40	.718	41	.708	41	.674	41	.628	38	- - -	- - -
12	.474	35	.470	35	.452	35	.428	35	.414	34	- - -	- - -
13	.310	36	.308	37	.302	39	.300	39	.246	40	- - -	- - -
14	.090	25	.092	25	.098	24	.074	23	.056	23	- - -	- - -
15	29.928	26	29.914	23	29.878	23	29.870	20	29.822	17	- - -	- - -
16	.694	21	.682	21	.658	20	.650	20	.600	18	- - -	- - -
17	.750	28	.764	26	.800	29	.800	29	.800	30	- - -	- - -
18	.900	32	.852	25	.858	25	.870	25	.872	25	- - -	- - -
19	.824	29	.812	25	.800	23	.818	23	.824	22	- - -	- - -
20	.912	23	.918	25	.922	27	.952	27	.982	26	- - -	- - -
21	30.192	32	30.190	32	30.184	32	30.180	30	30.058	28	- - -	- - -
22	29.812	25	29.850	25	29.838	25	29.824	25	29.822	26	- - -	- - -
23	30.000	30	30.024	31	30.038	30	30.024	30	30.000	27	- - -	- - -
24	.154	35	.176	35	.222	35	.312	32	.374	31	- - -	- - -
25	.730	37	.724	35	.744	35	.752	35	.600	35	- - -	- - -
26	.456	29	.324	34	.356	32	.276	29	.200	27	30in.154	24°
27	.172	37	.172	40	.200	40	.200	40	.182	37	- - -	- - -
28	.212	47	.242	42	.236	42	.236	42	.250	42	- - -	- - -
29	.132	44	.132	44	.076	41	.002	39	29.958	26	- - -	- - -
30	29.980	52	29.978	50	29.976	49	29.978	42	30.505?	46	- - -	- - -
Means	30.095	31.0	30.093	30.5	30.101	30.4	30.096	29.5	30.094	28.5		

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait. December, 1860.

Day of the month.	2h		4		6		8		10		Noon	
1	- - -	- - -	- - -	- - -	- - -	- - -	30in.216	40°	30in.297	45°	30in.299	42°
2	- - -	- - -	- - -	- - -	- - -	- - -	.487	39	.474	39	.472	39
3	- - -	- - -	- - -	- - -	- - -	- - -	.162	37	.106	38	.062	40
4	29in.865	33°	29in.838	30°	29in.836	30°	29.824	33	29.785	35	29.745	34
5	- - -	- - -	- - -	- - -	- - -	- - -	.711	34	.712	34	.714	36.5
6	- - -	- - -	- - -	- - -	- - -	- - -	.810	30	.778	30	.786	29
7	- - -	- - -	- - -	- - -	- - -	- - -	.704	16	.774	19	.774	18
8	- - -	- - -	- - -	- - -	- - -	- - -	.783	37	.802	30	.806	29
9	- - -	- - -	- - -	- - -	- - -	- - -	.704	15	.711	16	.718	17
10	- - -	- - -	- - -	- - -	- - -	- - -	.676	0	.674	−1	.744	76[1]
11	- - -	- - -	- - -	- - -	- - -	- - -	.863	72	.896	76	.963	71
12	- - -	- - -	- - -	- - -	- - -	- - -	30.298	61	30.250	60	30.274	68
13	30.368	68	30.317	58	30.268	52	.321	68.5	.257	71	.229	80
14	- - -	- - -	- - -	- - -	- - -	- - -	.000	62	.016	73	.038	73
15	- - -	- - -	- - -	- - -	- - -	- - -	29.889	64	29.871	67	29.815	64
16	- - -	- - -	- - -	- - -	- - -	- - -	.676	68	.612	68	.546	68
17	- - -	- - -	- - -	- - -	- - -	- - -	.727	72	.749	67	.752	64
18	- - -	- - -	- - -	- - -	- - -	- - -	30.145	60	30.133	63	30.038	67
19	30.059	55	30.073	55	30.132	61	.192	63	.168	60	.162	60
20	- - -	- - -	- - -	- - -	- - -	- - -	.311	73	.303	58	.386	61
21	- - -	- - -	- - -	- - -	- - -	- - -	.735	65	.702	60	.672	62
22	- - -	- - -	- - -	- - -	- - -	- - -	.599	69	.634	61	.691	70
23	- - -	- - -	- - -	- - -	- - -	- - -	.424	60	.400	61	.352	61
24	- - -	- - -	- - -	- - -	- - -	- - -	.456	56	.450	57	.552	68
25	30.677	53	30.706	52	30.718	49	.740	64	.772	69.5	.786	70
26	- - -	- - -	- - -	- - -	- - -	- - -	.642	64.5	.488	67	.493	66
27	- - -	- - -	- - -	- - -	- - -	- - -	.413	81	.392	70	.390	62.5
28	- - -	- - -	- - -	- - -	- - -	- - -	.354	54	.364	71	.373	74
29	- - -	- - -	- - -	- - -	- - -	- - -	.140	63	.082	57.5	.098	80
30	- - -	- - -	- - -	- - -	- - -	- - -	29.749	72	29.726	67	29.750	73
31	- - -	- - -	- - -	- - -	- - -	- - -	.910	63	.872	57	.818	60
Means							30.118	53.4	30.105	53.1	30.106	57.5

[1] Barometer brought below and hung in the companion-way.

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait.
December, 1860.

Day of the month.	2^h		4		6		8		10		Midnight.	
1	30in.312	42°	30in.324	42°	30in.346	42°	30in.352	42°	30in.368	42°	- - -	- - -
2	.456	40	.432	38	.453	41	.416	38	.360	37	- - -	- - -
3	.078	40	.065	40	.008	38	29.986	37	29.945	36	29in.895	34°
4	29.736	34	29.728	34	29.742	35	.722	31	.722	31	- - -	- - -
5	.718	37	.724	43	.749	40	.752	40	.762	36	- - -	- - -
6	.795	28	.776	28	.748	28	.750	25	.758	20	- - -	- - -
7	.756	18	.750	15	.748	15	.732	15	.720	14	- - -	- - -
8	.844	28	.810	22	.812	21	.772	19	.750	15	- - -	- - -
9	.685	13	.685	13	.760	15	.742	15	.715	14	- - -	- - -
10	.817	76	.837	72	.836	72	.817	72	.874	74	- - -	- - -
11	30.010	74	30.070	62	30.092	62	30.128	63	30.137	64	- - -	- - -
12	.320	70	.320	64	.398	71	.364	69	.386	66	30.387	74
13	.169	71	.124	60	.100	64	.056	65	.012	68	- - -	- - -
14	.040	69	.070	73	.057	69	.035	68	.023	67	- - -	- - -
15	29.882	65	29.902	71	29.882	69	29.864	66	29.830	64	- - -	- - -
16	.469	68	.321	64	.265	60	.266	61	.261	63	- - -	- - -
17	.806	70	.852	65	.894	61	.946	64	30.063	69	- - -	- - -
18	30.096	79	30.106	72	30.064	64	30.006	61	29.999	59	30.057	57
19	.143	65	.163	79	.104	73	.088	68	30.199	70.5	- - -	- - -
20	.588	62	.622	73	.684	72	.724	69	.757	66	- - -	- - -
21	.613	61	.558	55	.549	61	.563	66	.566	69	- - -	- - -
22	.684	67	.682	61	.676	56	.682	65	.652	62	- - -	- - -
23	.270	57	.241	56	.212	55.5	.183	55	.154	54	- - -	- - -
24	.565	70	.614	66	.648	58	.712	64	.676	58	30.694	55
25	.806	71	.800	70	.819	71	.773	70	.796	62	- - -	- - -
26	.500	67	.476	69	.452	65	.406	61.5	.334	62	- - -	- - -
27	.413	81	.423	71	.443	76	.338	67	.400	72.5	- - -	- - -
28	.414	72	.398	63.5	.372	66	.350	64.5	.322	63	- - -	- - -
29	.018	72	.081	71	29.985	69	29.916	67	29.858	63	- - -	- - -
30	29.762	79.5	29.740	66.5	.750	68.5	.756	65	.772	64.5	- - -	- - -
31	.846	74	.762	70	.740	64	.668	63	.644	67	29.550	59
Means	30.116	58.7	30.111	56.4	30.109	55.6	30.092	54.7	30.091	54.0		

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait.
January, 1861.

Day of the month.	2h		4		6		8		10		Noon	
1	29in.522	60°.5	29in.513	64°	29in.516	67°	29in.556	63°	29in.549	61°	29in.563	67°
2	---	---	---	---	---	---	---	---	.486	67	.550	60
3	---	---	---	---	---	---	.508	68	.530	73	.601	72
4	---	---	---	---	---	---	.780	70	.792	64	.800	56
5	---	---	---	---	---	---	30.085	72	30.046	66	30.013	73
6	---	---	---	---	---	---	29.970	70.5	29.974	72	29.962	59.5
7	---	---	---	---	---	---	.624	70	.688	67	.580	54
8	29.950	63	30.064	65	30.066	63.5	30.142	71	30.186	76	30.232	67
9	---	---	---	---	---	---	29.910	62	29.945	76	29.898	75
10	---	---	---	---	---	---	.716	64	.730	74	.770	71
11	---	---	---	---	---	---	30.356	72	30.390	75	30.420	72
12	---	---	---	---	---	---	.288	68	.108	67	29.982	69
13	---	---	---	---	---	---	29.488	74	29.348	65	.292	60
14	---	---	---	---	---	---	.516	65	.550	73.5	.568	65
15	29.504	57	29.550	54	29.500	51	.542	64	.593	65	.606	69
16	---	---	---	---	---	---	30.116	71	30.216	83.5	30.234	76
17	---	---	---	---	---	---	.548	69	.500	68	.532	66
18	---	---	---	---	---	---	.384	70	.372	67	.338	65.5
19	---	---	---	---	---	---	.318	67	.310	77	.306	76
20	---	---	---	---	---	---	.174	66	.130	68.5	.114	68
21	---	---	---	---	---	---	29.950	73	29.956	72	29.950	68
22	30.144	53	30.112	52.5	30.112	46	30.122	60	30.172	63	30.182	61
23	---	---	---	---	---	---	.124	70	.102	80	.066	65
24	---	---	---	---	---	---	29.934	59	29.988	73	29.980	70
25	---	---	---	---	---	---	.836	59.5	.756	64.5	.708	60
26	---	---	---	---	---	---	.734	78	.698	67	.681	69
27	---	---	---	---	---	---	.908	71	.900	57.5	.940	73
28	---	---	---	---	---	---	30.078	65	30.056	69	30.084	81
29	29.892	65	29.880	58.5	29.938	62	29.964	63.5	.028	88	.018	80
30	---	---	---	---	---	---	.882	59	29.886	70	29.908	83
31	---	---	---	---	---	---	30.072	73	30.092	79.	30.126	87
Means							29.939	67.3	29.938	70.6	29.936	69.0

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait. January, 1861.

Day of the month.	2^h		4		6		8		10		Midnight	
1	29.in606	74°	29in.601	71°	29in.624	66°	29in.536	66.°5	---	---	---	---
2	.443	65	.438	70	.442	71	.436	68	29in.420	68°	---	---
3	.572	73.5	.572	65	.590	65	.608	66.5	.610	60	---	---
4	.878	59.5	.968	62	30.012	65	30.028	68	30.054	71	---	---
5	.976	70	.956	75	29.900	74	29.890	74.5	29.868	66	---	---
6	.984	72	.965	79	.973	71	.968	70	.924	68	---	---
7	.620	70	.632	87	.666	76	.700	71	.824	71	29in.886	76°
8	30.268	74	30.274	74	30.250	68	30.250	74	30.236	75	---	---
9	29.886	76	29.850	70	29.812	75	29.806	73	29.788	65	---	---
10	.830	71.5	.988	65	.961	61	30.042	72	30.036	70	---	---
11	30.450	68	30.472	69	30.516	65.5	.494	65	.472	65.5	---	---
12	29.946	73	29.848	67	29.778	60	29.718	64	29.700	72	---	---
13	.266	75	.250	70.5	.268	74	.294	70	.282	67	---	---
14	.562	62	.606	71	.600	71.5	.620	70	.684	69	29.612	58
15	.748	75	.806	70	.926	73	.954	70	.978	67	---	---
16	30.256	74	30.300	68	30.345	67	30.382	61	30.424	67	---	---
17	.550	67	.510	70	.520	71	.500	70	.516	75	---	---
18	.364	71	.322	67	.318	67	.306	71	.300	69.5	---	---
19	.284	77	.282	67.5	.292	67	.284	68.5	.320	72	---	---
20	.124	64	.114	68.5	.082	68.5	.056	69	29.984	63.5	---	---
21	.025	67	.088	70	.064	66	.064	62	30.076	62	30.076	57.5
22	.170	61.5	.182	69	.182	73.5	.172	70	.164	67	---	---
23	.092	71	.052	64	.060	66	.040	70	.012	75.5	---	---
24	29.998	78	.013	76	29.944	72.5	29.944	79	29.950	75	---	---
25	.722	75	29.774	71	.776	73	.756	73	.758	72	---	---
26	.726	75	.756	65.5	.622	59	.672	57	.662	73.5	---	---
27	.994	70	30.012	67	30.028	66	30.038	67	30.076	73	---	---
28	30.000	68.5	29.992	78	.032	77	29.984	84	29.946	83	29.932	71
29	29.950	68	.962	79	29.944	78	.920	77	.874	72	---	---
30	.922	66	.909	70	.929	67	30.000	67	.946	67.5	---	---
31	30.058	69	30.098	83.5	30.084	67	.068	68	30.052	70	---	---
Means	29.944	70.3	29.956	70.9	29.953	69.1	29.953	69.6	29.951	69.6		

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait. February, 1861.

Day of the month.	2h		4		6		8		10		Noon	
1	- - -	- - -	- - -	- - -	- - -	- - -	29in.876	68°	29in.762	64°	29in.640	70°
2	- - -	- - -	- - -	- - -	- - -	- - -	.772	70	.824	75	.831	73
3	- - -	- - -	- - -	- - -	- - -	- - -	30.132	78	30.132	75	30.138	70
4	- - -	- - -	- - -	- - -	- - -	- - -	.118	67	.062	64	29.968	67
5	29in.980	72°	29in.992	65°	29in.974	58°	29.988	64	.026	71	30.052	70
6	- - -	- - -	- - -	- - -	- - -	- - -	.850	74	29.892	78	29.846	69
7	- - -	- - -	- - -	- - -	- - -	- - -	30.030	69	30.048	62	30.014	57
8	- - -	- - -	- - -	- - -	- - -	- - -	29.762	62.5	29.800	70	29.816	71
9	- - -	- - -	- - -	- - -	- - -	- - -	.950	72	.900	73	.782	70
10	- - -	- - -	- - -	- - -	- - -	- - -	.168	75	.100	75	.088	70
11	- - -	- - -	- - -	- - -	- - -	- - -	.630	57.5	.652	60	.648	53
12	29.884	57	29.900	50	30.002	45	30.048	50	30.098	60	30.126	59
13	- - -	- - -	- - -	- - -	- - -	- - -	.296	67	.262	64	.256	66
14	- - -	- - -	- - -	- - -	- - -	- - -	29.850	41.5	29.898	60	29.888	64
15	- - -	- - -	- - -	- - -	- - -	- - -	.924	65	30.000	75	30.020	70
16	- - -	- - -	- - -	- - -	- - -	- - -	.870	45	29.914	53	29.924	66
17	- - -	- - -	- - -	- - -	- - -	- - -	.900	87	.940	65	.922	68
18	- - -	- - -	- - -	- - -	- - -	- - -	.880	62	.958	76	.930	70
19	29.894	61.5	29.850	57	29.808	54	.750	67	.718	66	.700	69.5
20	- - -	- - -	- - -	- - -	- - -	- - -	.640	55.5	.678	69	.708	72
21	- - -	- - -	- - -	- - -	- - -	- - -	.800	69	.824	62	.904	60
22	- - -	- - -	- - -	- - -	- - -	- - -	30.032	60	30.000	56.5	30.018	63
23	- - -	- - -	- - -	- - -	- - -	- - -	.012	62	- - -	- - -	.042	72
24	- - -	- - -	- - -	- - -	- - -	- - -	29.878	74.5	29.840	66	29.838	73.5
25	- - -	- - -	- - -	- - -	- - -	- - -	.688	62.5	.668	74.5	.650	74.5
26	- - -	- - -	- - -	- - -	- - -	- - -	.464	49	.526	69	.560	74
27	- - -	- - -	- - -	- - -	- - -	- - -	.632	47	.718	74	.716	71
28	- - -	- - -	- - -	- - -	- - -	- - -	.674	61	.686	68	.624	69.5
Means							29.843	63.6	29.855	67.5	29.844	67.9

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait.
February, 1861.

Day of the month.	2^h		4		6		8		10		Midnight.	
1	29in.592	78°	29in.616	81°	29in.624	80°	29in.638	79°	29in.642	71°	---	---
2	.968	78	30.032	73	30.036	71.5	30.042	71	30.036	72	---	---
3	30.130	67	.126	61.5	.160	73	.150	72	.186	67	---	---
4	29.992	75	.018	88	29.972	79	29.968	80	29.900	78	29in.926	78°
5	30.078	65	.094	69	30.078	80	30.092	76	.978	95	---	---
6	29.824	76	29.838	79.5	29 828	77.5	29.822	76	.856	78	---	---
7	30.024	62	30.032	83	30.012	55	30.062	69	30.008	71	---	---
8	29.866	73	29.900	71	29.912	61	29.974	65	.018	72	---	---
9	.656	66	.556	61	.458	71	.512	76	29.458	72	---	---
10	.134	75	.212	74	.450	69	.442	68	.438	67	---	---
11	.728	59	.782	72.5	.864	65	.924	64	.916	64.5	29.952	62.5
12	30.140	54	30.246	60	30.288	68	30.292	70	30.304	65	---	---
13	.168	69	.204	69	.178	72	.154	88	.074	76	---	---
14	29.848	55	29.848	58	29.896	78	29.900	75	29.912	73	---	---
15	30.000	65	---	---	30.064	72	30.050	66	30.048	70	---	---
16	29.914	73	.860	68	29.868	67	29.850	62	29.832	67	---	---
17	.918	71	.962	78	.930	78	.939	78	.926	73	---	---
18	30.000	77.5	.984	69	30.028	74 5	30.000	70.5	30.100	72	29.956	66
19	29.708	80.5	.686	80	29.680	75	29.692	75.5	29.676	70.5	---	---
20	.688	69	---	---	.689	69	.730	66	.762	72.5	---	---
21	.850	60	.884	75	.912	65	.924	65	.988	75	---	---
22	30.037	72	30.054	75	30.052	78	30.038	70	30.060	64	---	---
23	.030	72	.000	72	.020	75	.008	75.5	29.988	71.5	---	---
24	29.818	69	29.838	65	29.800	69	29.776	51	.796	62	---	---
25	.636	69	.612	69	.662	83	.628	78	.596	67	---	---
26	.512	74	.518	87	.538	74	.538	70	.512	74	---	---
27	.700	67	.726	69	.750	71	.762	75	.746	69	---	---
28	.636	78	.620	64	.700	86	.638	70	.658	69.5	---	---
Means	29.843	69.6	29.856	71.7	29.873	72.7	29.877	71.5	29.872	71.0		

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait
March, 1861.

Day of the month.	2h		4		6		8		10		Noon	
1	---	---	---	---	---	---	29in.626	57°.5	29in.678	64°	29in.734	76°
2	---	---	---	---	---	---	.638	56	.692	64.5	.694	66.5
3	---	---	---	---	---	---	.706	55	.792	75	.808	79
4	---	---	---	---	---	---	.644	63 5	.640	64	.674	65.5
5	29in.588	51°.5	29in.568	47°	29in.504	42°	.508	45	.480	59	.438	58
6	---	---	---	---	---	---	.386	58	---	---	.434	62.5
7	---	---	---	---	---	---	.476	56.5	.514	69	.520	71
8	---	---	---	---	---	---	.500	60	.480	62.5	.520	68.5
9	---	---	---	---	---	---	.698	62	.684	65	.652	66.5
10	---	---	---	---	---	---	.538	60.5	.644	79	.704	79
11	---	---	---	---	---	---	.870	61	.790	60.5	.794	74
12	---	---	---	---	---	---	30.064	55	30.094	72	30.074	67
13	---	---	---	---	---	---	29.862	71	29.860	78	29.874	76
14	---	---	---	---	---	---	.948	59	.924	76	.900	72
15	---	---	---	---	---	---	.792	52	.814	57	.880	79
16	---	---	---	---	---	---	30.126	46.5	30.146	61	30.148	69.5
17	---	---	---	---	---	---	.000	57	.014	65	29.986	63
18	---	---	---	---	---	---	29.672	56	29.604	49	.632	57
19	---	---	---	---	---	---	30.008	46	30.032	56.5	30.056	59
20	---	---	---	---	---	---	29.918	43	29.948	61	.024	78
21	---	---	---	---	---	---	30.112	60	30.124	64	.166	69
22	---	---	---	---	---	---	.034	49.5	.082	68	.128	74
23	---	---	---	---	---	---	.266	56	.302	62	.416	69.5
24	---	---	---	---	---	---	.122	49	.106	57	.138	66
25	---	---	---	---	---	---	.400	51.5	.446	64	.442	59
26	---	---	---	---	---	---	.318	67	.232	61	.230	69.5
27	---	---	---	---	---	---	29.808	54.5	29.818	57	29.766	67
28	---	---	---	---	---	---	30.310	76	30.340	65	30.428	74
29	---	---	---	---	---	---	.568	60	.560	70.5	.500	73.5
30	---	---	---	---	---	---	29.850	66	29.806	65	29.808	69.5
31	---	---	---	---	---	---	.864	56	.950	73	.962	72
Means							29.891	57.0	29.903	64 7	29.920	69.4

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait.
March, 1861.

Day of the month.	2^h		4		6		8		10		Midnight.	
1	$29^{in}.652$	60°	$29^{in}.686$	72°	$29^{in}.680$	72°	$29^{in}.676$	72°	$29^{in}.660$	71°.5	---	---
2	.706	68	.732	70	.736	71	.714	69	.720	69	---	---
3	.772	72.5	.760	72	.760	68	.762	75.5	.730	68	---	---
4	.686	73	.712	70	.828	74	.692	72	.686	71.5	$29^{in}.650$	65°.5
5	.419	70	.428	74	.398	69	.352	61	.342	69	---	---
6	.462	64.5	.466	63	.522	73	.514	67	.506	67	---	---
7	.528	79	.576	74	.572	79	.628	83	.600	78	---	---
8	.522	71	.514	71.5	.618	69	.672	67.5	.712	70	---	---
9	.618	71.5	.592	77	.576	72	.564	76	.506	73.5	---	---
10	.764	75	.864	77	.988	80	30.014	79	30.006	68	---	---
11	.796	73.5	.854	70	.910	61.5	29.918	59	.014	64	---	---
12	30.030	62	30.062	68	30.046	73	30.042	73	.002	68.5	---	---
13	29.848	69	29.884	61	29.914	72	29.954	72	29.958	74.5	---	---
14	.954	75	.870	67	.902	71.5	.868	70.5	.838	65	---	---
15	.850	56	---	---	30.000	65	30.072	68	30.072	66.5	---	---
16	30.042	67	30.042	67	.028	69.5	29.988	72	29.994	74.5	---	---
17	.004	71.5	29.892	66	.002	70	.962	65.5	.974	65	---	---
18	29.608	55	.604	56	29.738	63	.788	65.5	.832	64.8	---	---
19	30.009	67	30.010	70	30.052	69.5	30.076	62	30.002	60.5	---	---
20	.012	71.5	.014	57.5	.042	56	.072	67.5	.012	67	---	---
21	.160	69.5	.134	63.5	.124	72	.108	69.5	.074	61	---	---
22	.154	66	.178	68	.234	67	.254	74	.242	70	---	---
23	.304	67	.284	63	.294	74.5	.268	69.5	.272	64	---	---
24	.150	64	.154	67.5	.168	68	.204	69	.244	71	---	---
25	.484	70	.514	58	---	---	.492	69.5	.462	69	---	---
26	.196	68	.168	66	.146	64	.138	75	.100	79.5	---	---
27	29.818	72	29.794	58	29.800	59	29.858	66	29.886	62.5	---	---
28	30.462	76	30.514	75	30.522	60.5	30.548	60	30.648	74	---	---
29	.462	74	.365	72	.304	70	.184	63	.158	65.5	---	---
30	29.780	70	29.818	60	29.842	77	29.844	67	29.834	66	---	---
31	.934	66	.926	55.5	.976	69	30.000	75	.978	68	---	---
Means	29.909	68.9	29.914	66.8	29.943	69.1	29.943	69.5	29.938	68.6		

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait.
April, 1861.

Day of the month.	2^h		4		6		8		10		Noon.	
1	- - -	- - -	- - -	- - -	- - -	- - -	$29^{in}.770$	55°	$29^{in}.798$	63°.5	$29^{in}.844$	72°
2	- - -	- - -	- - -	- - -	- - -	- - -	30.200	61	30.322	69	30.332	66
3	- - -	- - -	- - -	- - -	- - -	- - -	.294	60	.256	66	.238	72
4	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	.466	53.5	.564	59.5
5	- - -	- - -	- - -	- - -	- - -	- - -	.798	82	.758	70	.724	64
6	- - -	- - -	- - -	- - -	- - -	- - -	.494	68	.488	67	.488	67
7	- - -	- - -	- - -	- - -	- - -	- - -	.520	65	.558	76.5	.554	71
8	- - -	- - -	- - -	- - -	- - -	- - -	.312	67	.236	65.5	.222	63
9	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	.284	69.5	.260	57
10	- - -	- - -	- - -	- - -	- - -	- - -	.138	61	.130	61	.136	51.5
11	- - -	- - -	- - -	- - -	- - -	- - -	.378	69	- - -	- - -	.180	50
12	- - -	- - -	- - -	- - -	- - -	- - -	29.847	57	29.880	65	29.908	66
13	- - -	- - -	- - -	- - -	- - -	- - -	.832	58	.880	65	.920	76
14	- - -	- - -	- - -	- - -	- - -	- - -	30.054	63	30.052	63	30.070	61
15	- - -	- - -	- - -	- - -	- - -	- - -	.208	60	- - -	- - -	.212	56.5
16	- - -	- - -	- - -	- - -	- - -	- - -	.150	63	.144	62	.140	56
17	- - -	- - -	- - -	- - -	- - -	- - -	29.880	65	29.850	60	- - -	- - -
18	- - -	- - -	- - -	- - -	- - -	- - -	30.222	52.5	30.212	60	.196	60
19	- - -	- - -	- - -	- - -	- - -	- - -	29.946	66.5	29.910	60.5	29.852	64
20	- - -	- - -	- - -	- - -	- - -	- - -	.542	67	.538	68	.592	69
21	- - -	- - -	- - -	- - -	- - -	- - -	.824	73	.828	60	.842	53
22	- - -	- - -	- - -	- - -	- - -	- - -	30.208	56	30.206	64	30.130	58
23	- - -	- - -	- - -	- - -	- - -	- - -	29.778	56	29.796	56.5	29.830	58
24	- - -	- - -	- - -	- - -	- - -	- - -	.992	50	30.000	57	30.068	73
25	- - -	- - -	- - -	- - -	- - -	- - -	.940	60	29.890	58.5	29.888	51
26	- - -	- - -	- - -	- - -	- - -	- - -	30.232	54	30.228	60	30.222	64
27	- - -	- - -	- - -	- - -	- - -	- - -	.268	65.5	.275	70	.292	69
28	- - -	- - -	- - -	- - -	- - -	- - -	.488	68	.444	62.5	.452	65
29	- - -	- - -	- - -	- - -	- - -	- - -	.400	70	.352	65.5	.342	60
30	- - -	- - -	- - -	- - -	- - -	- - -	.092	55	.100	65	.062	68
Means							30.150	62.3	30.145	63.4	30.148	62.8

Readings of the barometer and attached thermometer near and at Port Foulke, Smith Strait. April, 1861.

Day of the month.	2^h		4		6		8		10		Midnight.	
1	$29^{in}.838$	63°	$29^{in}.890$	68°	$29^{in}.940$	71°.5	$29^{in}.976$	68°	$30^{in}.006$	73°	---	---
2	30.346	56	30.352	58	30.338	46	30.382	59	.398	69	---	---
3	.214	77	.196	66	.212	69	.196	66	.200	64.5	---	---
4	.592	60	---	---	.684	61.5	.680	52.5	.624	51	---	---
5	.708	68	---	---	.654	60	.616	56.5	.564	49	---	---
6	.480	68	.490	66.5	.502	68	.538	70	---	---	---	---
7	.550	67	---	---	.530	66.5	.508	63	.444	53	---	---
8	.188	68	.198	53	.202	54	---	---	.224	51.5	---	---
9	.248	51.5	.264	57	.260	57	---	---	.182	51	---	---
10	---	---	---	---	.258	60	.300	64	.344	66	---	---
11	.100	55.5	---	---	29.964	67	29.910	62	29.900	61	---	---
12	29.842	56	29.886	49.5	.900	48	.920	63	.900	60	---	---
13	.902	67.5	.926	53.5	.992	64	.994	63	30.000	58	---	---
14	30.096	70	30.124	72	30.138	73	30.142	70	---	---	---	---
15	.192	55	---	---	---	---	---	---	.116	46	---	---
16	.100	47	.092	---	.086	60	---	---	---	---	---	---
17	29.946	64	.086	68.5	.234	66.5	.284	58.5	.340	64	---	---
18	30.194	59	---	---	.132	63	---	---	.100	65	---	---
19	29.692	66	29.624	48	29.600	50	29.592	62	29.570	65.5	---	---
20	.596	68.5	.600	67	.594	57	.584	57.5	---	---	---	---
21	.948	67	.992	67	30.080	67	30.144	66	30.192	61	---	---
22	30.126	58	30.100	60	.040	66	.004	64	29.992	60	---	---
23	29.890	64	29.872	57	29.908	57	29.908	53	.900	52	---	---
24	30.068	62.5	30.050	60	30 038	60	30.036	59.5	30.022	56	---	---
25	29.896	50	29.908	48.5	29.942	48	.000	55	.078	56	---	---
26	30.188	54	30.174	55	30.194	60	.208	56.5	.252	54	---	---
27	.272	62	.274	65	.290	52	.348	55.5	.356	60	---	---
28	.432	61	.432	61	.444	56	.450	65	---	---	---	---
29	.324	62	.294	58	.232	52	.234	63	.224	64.5	---	---
30	.024	63	29.974	56	29.926	52	29.986	68	.060	63	---	---
Means	30.139	61.5	30.141	59.7	30.149	59.4	30.156	60.7	30.158	59.9		

Readings of the barometer and attached thermometer near and at Port Foulke, Smith Strait. May, 1861.

Day of the month.	2h		4		6		8		10		Noon.	
1	---	---	---	---	---	---	29in.938	60°	---	---	29in.968	60°
2	---	---	---	---	---	---	30.018	76	29in.912	68°	.856	69
3	---	---	---	---	---	---	.138	55	30.096	50.5	30.068	48
4	---	---	---	---	---	---	.272	58	.324	64	.362	65
5	---	---	---	---	---	---	.636	50	.638	52	.662	67
6	---	---	---	---	---	---	.394	62.5	.386	60	.374	58.5
7	---	---	---	---	---	---	.484	49	.508	55	.492	53
8	---	---	---	---	---	---	.352	61.5	.398	65.5	.362	65
9	---	---	---	---	---	---	.444	49	.432	49	.428	56
10	---	---	---	---	---	---	.232	43	.208	44	.202	52.5
11	---	---	---	---	---	---	.268	65	.278	67.5	.252	72
12	---	---	---	---	---	---	.110	58.5	.122	71.5	.132	73
13	---	---	---	---	---	---	.268	55	.280	51.5	.294	51.5
14	---	---	---	---	---	---	.348	56	.320	60	.346	67
15	---	---	---	---	---	---	.230	51	.250	66	.246	61.5
16	---	---	---	---	---	---	.366	49	.348	53	.352	55
17	---	---	---	---	---	---	.022	47	29.976	51	29.900	51
18	---	---	---	---	---	---	29.964	42	.954	45	.964	53
19	---	---	---	---	---	---	.888	58	.868	58	.884	74
20	---	---	---	---	---	---	.726	49	.750	69	.746	69.5
21	---	---	---	---	---	---	.668	49	.732	61	.734	52.5
22	---	---	---	---	---	---	30.038	51.5	30.068	60	30.068	58
23	---	---	---	---	---	---	.006	57	---	---	29.970	45
24	---	---	---	---	---	---	29.876	50	29.860	55	.866	53
25	---	---	---	---	---	---	.926	57.5	.894	55	.906	53
26	---	---	---	---	---	---	.900	52	.816	53	---	---
27	---	---	---	---	---	---	.688	56	.656	60.5	.642	59
28	---	---	---	---	---	---	.644	58	.692	58.5	.792	58
29	---	---	---	---	---	---	.736	48	.710	49	.742	55.5
30	---	---	---	---	---	---	.800	58	.782	50	.766	50
31	---	---	---	---	---	---	.718	43.5	.712	45	.762	63.5
Means							30.068	54.0	30.062	56.8	30.064	58.8

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait.
May, 1861.

Day of the month.	2h		4		6		8		10		Midnight.	
1	29.in922	52°	29in.904	52°	29in.942	44°	29in.986	59°	30in.020	63°	---	---
2	.800	70	.798	62	.786	55	.876	51	.008	67	---	---
3	30.066	66	30.072	68	30.082	64	---	---	.180	65	---	---
4	.412	64	.448	63	.464	71	30.522	67	.546	61.5	---	---
5	---	---	.614	64	.600	60	.580	62	.542	64	---	---
6	.418	60	.428	67	.438	66	.456	68	.472	68	---	---
7	.474	55	.474	63	.476	66.5	.432	67	.414	68.5	---	---
8	.374	65	.418	65	.428	66	.450	62	.452	65	---	---
9	.416	49.5	.424	49.5	.398	48	.372	50	.362	55	---	---
10	.250	68	.232	71	.234	71.5	.220	66	.224	66	---	---
11	.248	65	.240	66	.212	59.5	.200	62	.190	64	---	---
12	.164	74	.176	69	.194	70	.204	63.5	.218	63	---	---
13	.292	50	---	---	.340	53	.376	55	---	---	---	---
14	.300	61	.274	63.5	.272	63	.246	63	.264	65	---	---
15	.252	67	.266	65	.284	66	.318	69	.336	66	---	---
16	.356	54.5	.322	57	.308	59	.270	54	.238	57	---	---
17	29.924	48	29.938	55	29.948	60	29.950	53	29.966	55	---	---
18	.988	64	.986	60.5	.962	59.5	.932	64	.940	71	---	---
19	.842	57	.828	65.5	.844	64	.812	65.5	.812	64	---	---
20	.742	68	.716	66	.728	64	.674	73	.664	66	---	---
21	.748	50	.814	54	.874	61	.928	63.5	.958	62.5	---	---
22	30.066	52	30.074	48	30.068	53	30.058	61	30.048	56	---	---
23	29.936	50.5	.010	70	29.972	71.5	29.968	72	29.954	70	---	---
24	.882	58	29.880	63	.886	53	.906	61.5	.896	54	---	---
25	.880	49.5	.924	55	.924	56	.936	62	.928	63	---	---
26	.866	51	.886	50.5	.854	50	.796	50.5	.780	49	---	---
27	.606	56.5	.560	46.5	.554	48.5	.560	48	.566	54.5	---	---
28	.786	58	.814	55	.812	52	.808	52	.780	57.5	---	---
29	.742	57.5	.712	54	.720	50.5	.728	50.5	.720	50.5	---	---
30	.772	52	.788	59	.776	56	.766	53	.770	55	---	---
31	.736	53.5	.754	54.5	.754	55	.750	55.5	.774	55	---	---
Means	30.061	58.4	30.069	59.8	30.069	59.2	30.071	60.3	30.077	61.2		

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait.
June, 1861.

Day of the month.	2^h		4		6		8		10		Noon.	
1	---	---	---	---	---	---	$29^{in}.738$	49°	$29^{in}.706$	45°	$29^{in}.692$	45°
2	---	---	---	---	---	---	.640	50	.638	52.5	.636	52
3	---	---	---	---	---	---	.592	52	.582	55	.578	56
4	---	---	---	---	---	---	.684	55	.708	57	.710	59
5	---	---	---	---	---	---	.688	47	.684	46	.694	47
6	---	---	---	---	---	---	.560	46	.508	43.5	.500	45
7	---	---	---	---	---	---	.678	51	.698	58	.670	58
8	---	---	---	---	---	---	.748	53	.712	41	.672	41
9	---	---	---	---	---	---	.608	45.5	.642	65	.638	65
10	---	---	---	---	---	---	.626	46	---	---	.584	50
11	---	---	---	---	---	---	.748	53.5	.734	49	.728	49
12	---	---	---	---	---	---	.860	48	.900	54	.916	55
13	---	---	---	---	---	---	.956	62	.938	53	.944	51
14	---	---	---	---	---	---	.999	46	.930	50	.932	49
15	---	---	---	---	---	---	30.056	61	---	---	---	---
16	---	---	---	---	---	---	29.816	59	.814	62	.782	61
17	---	---	---	---	---	---	30.020	57	30.032	55	30.048	53
18	---	---	---	---	---	---	.006	54	.002	63.5	.004	63.5
19	---	---	---	---	---	---	29.740	47.5	29.700	53.5	29.778	49
20	---	---	---	---	---	---	.844	53	.921	52	.890	49
21	---	---	---	---	---	---	30.024	55	30.032	56	30.022	57
22	---	---	---	---	---	---	29.966	51	29.948	56	29.932	53
23	---	---	---	---	---	---	.898	54.5	.888	54	.884	55
24	---	---	---	---	---	---	.792	53	.734	54	.674	55
25	---	---	---	---	---	---	.584	55	.578	51.5	.534	52
26	---	---	---	---	---	---	.638	50	.654	53	.642	51
27	---	---	---	---	---	---	.559	49	.544	53.5	.546	56
28	---	---	---	---	---	---	.492	52	.500	56	.518	55.5
29	---	---	---	---	---	---	.500	50	.510	49	.421	58
30	---	---	---	---	---	---	.486	53	.500	62	.476	60.5
Means							29.751	51.9	29.746	53.5	29.736	53.5

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait.
June, 1861.

Day of the month.	2^h		4		6		8		10		Midnight.	
1	$29^{in}.692$	47°	$29^{in}.708$	53°	$29^{in}.706$	53°	$29^{in}.674$	54°	$29^{in}.688$	54°.5	---	---
2	.632	48.5	.612	48.5	.632	50.5	.632	49.5	.610	50	---	---
3	.616	57	.612	61	.604	56	.584	50	.584	48	---	---
4	.716	55	.730	50	.714	48	---	---	.760	62	---	---
5	.674	50	.688	50	.650	45	.654	49	.650	54	---	---
6	.522	42	.522	48	.540	47	.564	52	.508	50	---	---
7	.738	56	.694	51	.720	45	.734	48	.758	57	---	---
8	.692	48	---	---	.674	50	.692	51	.666	54	---	---
9	.654	56	.642	49.5	.658	49	---	---	.668	50.5	---	---
10	.542	53	.551	51	.548	51	.530	51	.522	57	---	---
11	.726	47	.738	50.5	.786	49	.786	53	.798	50	---	---
12	.960	54	.951	58	.942	55	30.020	54	---	---	---	---
13	---	---	.916	54	.924	52	29.948	54	.942	51	---	---
14	30.030	49	30.014	54	30.018	55	30.038	60	30.046	58	---	---
15	---	---	.016	50	.002	48	29.984	52	29.960	56	---	---
16	29.799	59	29.828	54	29.888	59	.912	58	---	---	---	---
17	30.026	55	30.004	54	30.036	54	30.023	53	30.044	53	---	---
18	29.986	62	29.946	55.5	29.928	53	29.898	51	29.892	50	---	---
19	.742	51	.779	57	.772	53	.768	51.5	.776	52	---	---
20	.820	51	.990	53	.996	51	---	---	.978	57	---	---
21	30.060	57	30.076	54	30.050	52	30.052	50.5	30.026	55	---	---
22	---	---	20.918	51	29.926	59	29.804	57	29.878	55	---	---
23	29.912	54	.914	54	.906	53	.888	53.5	.892	53	---	---
24	.670	57	.682	57	.674	55	.676	57	.670	54	---	---
25	.586	53	.568	54	.568	54	.594	54	.586	53	---	---
26	.522	54	.542	52	.632	54	.640	57	.614	56	---	---
27	.564	56.5	.544	57	.556	57	.546	56.5	.534	55.5	---	---
28	.516	58	.510	57.5	.524	55	.510	53.5	.502	52	---	---
29	.456	59	.443	55	.444	54	.404	61.5	.448	59	---	---
30	.466	59	.468	55	.492	61	.494	60.5	.472	58	---	---
Means	29.740	53.5	29.743	53.6	29.750	52.6	29.748	53.7	29.747	54.2		

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait.
July, 1861.

Day of the month.	2^h		4		6		8		10		Noon.	
1	- - -	- - -	- - -	- - -	- - -	- - -	$29^{in}.400$	55°	$29^{in}.420$	59°	$29^{in}.374$	56°
2	- - -	- - -	- - -	- - -	- - -	- - -	.504	57	.492	56	.466	57
3	- - -	- - -	- - -	- - -	- - -	- - -	.450	59	.484	57	.504	56.5
4	- - -	- - -	- - -	- - -	- - -	- - -	.716	55	- - -	- - -	.744	56
5	- - -	- - -	- - -	- - -	- - -	- - -	.708	50	- - -	- - -	.706	57
6	- - -	- - -	- - -	- - -	- - -	- - -	.356	48	.376	50.5	.440	54
7	- - -	- - -	- - -	- - -	- - -	- - -	.646	55.5	.640	56	.654	58
8	- - -	- - -	- - -	- - -	- - -	- - -	.682	57	.758	60	.816	61
9	- - -	- - -	- - -	- - -	- - -	- - -	30.038	56	.984	58	- - -	- - -
10	- - -	- - -	- - -	- - -	- - -	- - -	29.763	55	.692	54	.646	60
11	- - -	- - -	- - -	- - -	- - -	- - -	.900	56	.964	57.5	.932	60
12	- - -	- - -	- - -	- - -	- - -	- - -	.830	54	.888	59	.730	67
13	- - -	- - -	- - -	- - -	- - -	- - -	.992	57	- - -	- - -	30.186	58
14	- - -	- - -	- - -	- - -	- - -	- - -	.950	56	.988	56	29.974	54
15	$29^{in}.850$	53°	$29^{in}.836$	52°.5	$29^{in}.778$	53°	.818	57	.876	56	.956	54
16	30.046	47	.980	47	.984	48	.988	50	30.120	48	30.124	50
17	29.988	50	.994	50	.882	50	.926	50	29.903	50.5	.032	50
18	.870	52	.820	52	.832	50	.792	50	.842	50	29.810	51
19	.770	48	.750	50	.750	50	.650	50	.600	51.5	.630	71.5
20	.712	59	.722	57	.668	57	.658	58.5	.604	59	.618	54
21	.656	53.5	.682	54.5	.628	54.5	.612	55	.684	51	.744	78
22	.594	67	.569	55	.604	49	.612	52	.594	60	.600	75
23	.576	60	.568	56	.500	56	.450	58	.535	69.5	.589	76.5
24	.700	55	.710	54	.664	54	.662	53.5	- - -	- - -	.630	66
25	.590	60	.564	56	.622	53	.656	59	.650	73	.630	73
26	.818	67	.810	61	.770	59.5	.800	60.5	.826	69	.868	76
27	.930	56	.950	54	.888	53	.894	53	.958	58	.970	58
28	.828	52	.826	51	.812	50	.786	51	.780	52	- - -	- - -
29	.826	55	.848	56	.840	53	.850	54	.862	54	.842	54
30	.850	58.5	.870	56	.766	55.5	.836	56	.844	54	.870	56
31	30.028	55	30.025	54	.980	50	.990	52	30.100	53	30.100	56.5
Means							29.739	54.5	29.762	56.8	29.774	60.2

Readings of the barometer and attached thermometer at Port Foulke, Smith Strait
July, 1861.

Day of the month.	2h		4		6		8		10		Midnight.	
1	29in.364	58°	29in.372	58°	29in.370	58°	29in.342	56°	29in.346	55°	---	---
2	.428	57	.466	55	.452	53	.424	56	.418	58	---	---
3	.528	58	.570	56	.584	55	.612	62	.608	60	---	---
4	.776	58	---	---	.762	56	.820	58	.784	56.5	---	---
5	.700	58.5	.702	56.5	.656	57	.636	56	.546	53	---	---
6	.424	54	.498	59.5	.526	58	.516	57	---	---	---	---
7	.649	58.5	.644	58	.626	57	.617	56.5	.612	55.5	---	---
8	.886	63	---	---	.900	63	.904	58	.904	57	---	---
9	30.058	61	30.050	59.5	30.038	57	30.034	59	30.062	58	---	---
10	29.598	58	29.572	58	29.602	57	---	---	29.652	54	---	---
11	.928	56	.926	58	.924	58	29.900	57	.820	54	---	---
12	.776	56	.988	56	.992	58	30.044	60	---	---	---	---
13	30.129	57	30.057	57	30.058	57	.056	57	30.052	56	---	---
14	29.960	54	29.928	54	29.900	55	29.886	55	29.888	55	29in.884	53°
15	.893	54	.904	53	30.033	46	.950	47	.878	46	.950	45.5
16	.898	49	.985	50	29.878	51	.968	50	30.044	50	.933	52
17	.978	50	.900	45	.942	51	.876	51	29.954	51	.924	48
18	.808	53	.838	51	.855	51	.820	51	.750	45.5	.750	48
19	.673	66	.635	64	.681	84	.618	73	.635	63	.592	62.5
20	.634	54	.618	51	.672	53.5	.642	50	.704	55	.718	53
21	.682	70.5	.640	70	.590	63	.656	70	.608	60	.570	76
22	.563	67	.528	73	---	---	.500	72	.700	76	.521	72
23	.648	73	.616	77	.650	64	.614	57	.700	55	.700	55
24	---	---	.650	78	.715	74	.670	65	.650	72.5	.620	73
25	.682	76	.684	79	.788	78	.750	72.5	.756	69.5	.758	84
26	.928	75	.966	72	.880	65	.882	62	.938	61	.936	58
27	.870	54.5	.880	55	.870	55	.930	55	.850	54	.830	54
28	---	---	---	---	---	---	.750	53	.764	55.5	.758	56
29	.894	61	.934	71	.910	72	.848	72.5	.884	65	.868	58
30	.900	54	.900	54	.985	54	.970	50	30.000	50	30.005	53
31	30.054	57	.957	58	30.070	61	.900	56	29.962	52	29.863	51
Means	29.768	59.5	29.772	60.0	29.783	59.6	29.767	58.4	29.776	57.0		

Notes to the preceding Daily Record.

September. To obtain the monthly means for the hours midnight, 2, 4, and 6 A. M., the following process was adopted: The monthly means for the hours 8, 10, noon, 2, 4, 6, 8, 10 P. M., after supplying the few omissions by simple interpolation, were found $=29^{in}.686$ at 32°; for the same hours the mean for the days September 12 to September 30 $=29^{in}.695$ at 32°; hence the correction to the mean for each of the hours midnight, 2, 4, and 6 A. M., $= -0^{in}.009$, which renders the monthly averages for each observing hour strictly comparable. The few omissions in the last nineteen days for the hours from midnight to 6 were previously supplied by simple interpolation.

October. The monthly means for midnight, 2, 4, 6 A. M., were found by the same method as in preceding month; they depend on eight days of observations.

January to June. The occasional blanks in the record were supplied by interpolation.

July. The same principle of interpolation was applied for the hours midnight, 2, 4, 6 A. M., as in preceding September or October.

Resulting monthly averages of bi-hourly observations of the barometer; temperature reduced to 32°.

	2h	4	6	8	10	Noon	2	4	6	8	10	12h
September	29.690	29.681	29.685	29.695	29.679	29.682	29.684	29.689	29.687	29.686	29.685	29.686
October	.563	.584	.592	.616	.616	.619	.618	.618	.617	.625	.629	.658
November	- - -	- - -	- - -	30.086	30.086	30.079	30.088	30.087	30.096	30.094	30.094	- - -
December	- - -	- - -	- - -	.051	.039	.029	.035	.036	.037	.022	.023	- - -
January	- - -	- - -	- - -	29 835	29.825	29.827	29.832	29.842	29.844	29.843	29.841	- - -
February	- - -	- - -	- - -	.750	.751	.739	.734	.741	.756	.762	.759	- - -
March	- - -	- - -	- - -	.816	.807	.811	.801	.812	.835	.834	.832	- - -
April	- - -	- - -	- - -	30.059	30.051	30.056	30.050	30.057	30.066	30.070	30.073	- - -
May	- - -	- - -	- - -	30.000	29.987	29.983	29.981	29.985	29.986	29.985	29.989	- - -
June	- - -	- - -	- - -	29.689	.680	.670	.674	.677	.687	.682	.679	- - -
July	.707	.707	.677	.671	.687	.690	.686	.688	.730	.688	.701	.67[illegible]

Diurnal Fluctuation of the Atmospheric Pressure.

The diurnal fluctuation, on the yearly average, was deduced from the above table as follows: The readings for August were interpolated from the July and September readings; from the observations at Van Rensselaer Harbor, Port Kennedy, and Baffin Bay, August mean = July mean — $0^{in}.009$, also August mean = September mean —$0^{in}.040$; applying these reductions, and taking the mean of the two results, we find for August the readings:—

	2h	4	6	8	10	Noon	2	4	6	8	10	12h
August	29.674	29.670	29.656	29.658	29.658	29.661	29.661	29.664	29.684	29.662	29.668	29.656

To supply the annual means for the hours midnight, 2, 4, 6 A. M., we have mean of 8, 10, noon, 2, 4, 6, 8, 10 for July, August, September, October =29.668, and for the same hours, mean of the year =29.828, hence correction to the means of four months at the hours midnight, 2, 4, 6 A. M. to refer them to the annual value = + .160.

We have consequently for the whole year:—

	2h	4	6	8	10	Noon	2	4	6	8	10	12h
Year	29.818	29.820	29.812	29.826	29.822	29.820	29.820	29.825	29.835	29.829	29.831	29.829

If we subtract from these numbers their average value, we find the diurnal variation proper as given below, to which that of Van Rensselaer Harbor, Port Kennedy, and Baffin Bay ($\phi = 72.5$) have been added.

Diurnal fluctuation of the barometer.
(+ above mean, — below mean reading.)

Hour.	Port Foulke $\phi = 78° 18'$.	Van Rensselaer 78° 37'.	Port Kennedy 72° 01'.	Baffin Bay 72° 30'.
2	$-0^{in}.006$	$0^{in}.000$	$-0^{in}.019$	$-0^{in}.010$
4	—.004	+.001	—.028	—.013
6	—.012	+.001	—.031	—.017
8	+.002	—.003	—.002	—.012
10	—.002	—.001	+.010	+.007
Noon	—.004	—.002	+.008	.000
2	—.004	—.006	+.011	+.002
4	+.001	—.002	+.014	+.010
6	+.011	+.002	+.015	+.013
8	+.005	+.004	+.018	+.013
10	+.007	+.006	+.009	+.010
12	+.005	+.003	.000	.000

Expressed analytically the above diurnal fluctuations are given by the equations:—

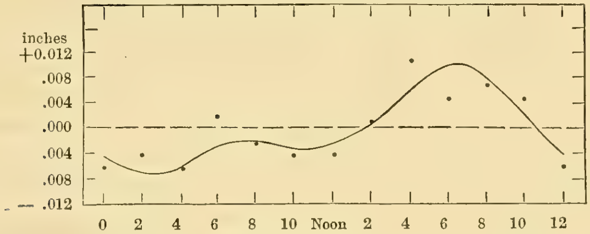
Port Foulke, $b = 0^{in}.006 \, sin \, (\theta + 159°) + 0^{in}.004 \, sin \, (2\theta + 186°)$
Van Rensselaer Harbor, $b = 0.003 \, sin \, (\theta + 110\ ) + 0.002 \, sin \, (2\theta + 204\ )$
Port Kennedy, $b = 0.021 \, sin \, (\theta + 202\ ) + 0.009 \, sin \, (2\theta + 150\ )$
Baffin Bay, $b = 0.013 \, sin \, (\theta + 185\ ) + 0.004 \, sin \, (2\theta + 159\ )$

The angle θ counts from *midnight* at the rate of 15° an hour.

The general correspondence of these expressions is quite satisfactory; the most striking feature is the rapid diminution of the diurnal fluctuation with an increase of latitude; thus the coefficients of either term for Van Rensselaer Harbor are one-half of those for Port Foulke, and taking the average for these localities ($\phi = 78° 28'$) we have a diurnal range of only 0.013 inch, whereas the upper range for Port Kennedy and Baffin Bay ($\phi = 72° 15'$) is 0.038 inch; if this rate of diminution continues, the range would be less than 0.001 inch in latitude $81\frac{1}{2}$°.

The observed and computed diurnal fluctuation at Port Foulke is shown by the annexed diagram.

Diurnal Fluctuation of the Atmospheric Pressure.



By the aid of the curve we find the maximum to occur about $6\frac{1}{2}$ P. M.; at Van Rensselaer it occurred about 10 P. M., and at Port Kennedy and Baffin Bay about $7\frac{1}{2}$ P. M.; the principal minimum occurs about 3 A. M., at Van Rensselaer the (secondary) minimum occurred about 4 A. M., and at Port Kennedy and Baffin Bay

about $4\frac{1}{2}$ A. M. At Port Foulke the secondary maximum and minimum occur about 8 and $10\frac{1}{2}$ A. M.: diurnal range 0.017 inch.

Annual Fluctuation of the Atmospheric Pressure.

The monthly mean values derived from the hours 8 A. M. to 10 P. M., which are strictly comparable, inter se, are as follows:—

September	$29.^{in}686$	March	$29^{in}.818$
October	29.620	April	30.060
November	30.089	May	29.987
December	30.034	June	29.680
January	29.836	July	29.693
February	29.749	August	29.664

The mean of these values is $29^{in}.826$, but the annual mean from 12 values a day was 29.824; we subtract therefore $0^{in}.002$ which gives the following monthly mean barometric pressure, and the annual fluctuation proper, + indicating greater, — less pressure than the mean amount.

Annual fluctuation of the atmospheric pressure.
Maximum marked by a *.

	Port Foulke.	Port Foulke.	Van Rensselaer.	Port Kennedy.	Baffin Bay.
January	$29^{in}.834$	$+0^{in}.010$	$+0^{in}.003$	$+0^{in}.041$	$-0^{in}.223$
February	29.747	—0.077	+0.073	—0.005	—0.106
March	29.816	—0.008	—0.025	+0.235	+0.138
April	30.058	+0.234*	+0.128	+0.241*	+0.185
May	29.985	+0.161	+0.167*	+0.072	+0.259*
June	29.678	—0.146	—0 056	—0.025	+0.062
July	29.691	—0.133	—0.034	—0.234	—0.002
August	29.662	—0.162	—0.081	—0.197	—0.019
September	29.684	—0.140	—0.117	—0.039	—0.020
October	29.618	—0.206	—0.020	—0.140	+0.001
November	30.087	+0.263*	—0.017	+0.114	—0.090
December	30.032	+0.208	—0.022	—0.066	—0.185

The true maximum occurs evidently in April, that of November being accidental. The spring maximum (April and May) is well marked for either locality. The minimum at Port Foulke occurred in October; at Van Rensselaer Harbor in September. Computed annual range at Port Foulke 0.40 inch; at Van Rensselaer Harbor 0.21 inch.

We have also the annual fluctuation at

Port Foulke,	$B = 0^{in}.120 \sin(\theta + 48^{\circ}) + 0^{in}.141 \sin(2\theta + 177^{\circ})$
Van Rensselaer Harbor,	$B = 0.079 \sin(\theta + 4) + 0.044 \sin(2\theta + 294)$
Port Kennedy,	$B = 0.137 \sin(\theta + 17) + 0.106 \sin(2\theta + 232)$
Baffin Bay,	$B = 0.155 \sin(\theta + 304) + 0.113 \sin(2\theta + 236)$

The angle θ counts from January 1st at the rate of 30° a month.

The formula for Port Foulke places a maximum about the commencement of May, and a minimum about the end of August; it requires, however, more than one year's observation to secure a reliable value of the annual fluctuation.

The annual range is twenty times greater than the diurnal range.

Mean Atmospheric Pressure at the Level of the Sea.

We obtained the annual average value of the atmospheric pressure $= 29^{in}.824$; the reduction to the sea level is $+0^{in}.006$, hence the height of the barometer at the sea level in latitude 78° 18′ = 29.830 inches.

At Van Rensselaer Harbor in latitude	78 37	29.775	"
" Port Kennedy " "	72 01	29.938	"
" Baffin Bay " "	72 30	29.755	"
Average,	$75\frac{1}{3}$	29.824	"

Monthly and Annual Extremes of Pressure.

The following table contains the observed maxima and minima of atmospheric pressure in each month; attached thermometer at 32°. The corresponding range at Van Rensselaer Harbor has been added for comparison.

	Maximum.	Minimum.	Port Foulke range.	Van Rensselaer Har. range.
September	$30^{in}.13$	$29^{in}.27$	$0^{in}.86$	$1^{in}.11$
October	30.22	28.94	1.28	1.28
November	30.74	29.59	1.15	1.30
December	30.71	29.17	1.54	1.48
January	30.45	29.14	1.31	1.36
February	30.20	28.98	1.22	1.61
March	30.53	29.23	1.30	1.31
April	30.61	29.44	1.17	1.09
May	30.58	29.50	1.08	1.30
June	30.01	29.31	0.70	0.78
July	30.11	29.27	0.84	0.57
August	- - - -	- - - -	0.85[1]	0.83
Mean			1.11	1.17

[1] Interpolated.

The monthly range is greatest in winter and least in summer.

Observed absolute maximum and minimum and extreme range, referred to 32° Fah., and at the level of the sea:—

Maximum	$30^{in}.74$	November 25, 1860
Minimum	28.93	October 16, 1860
Range	1.81	

The extreme range at Van Rensselaer Harbor was 2.13 inches.

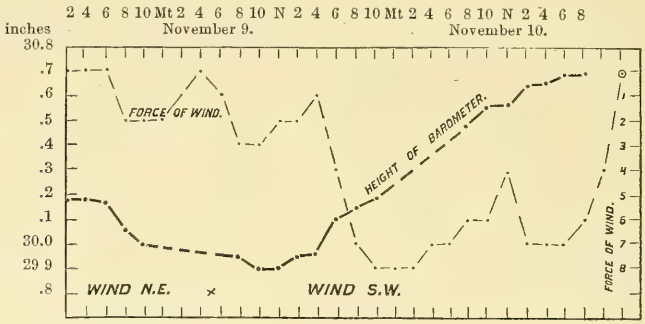
Relation of the Atmospheric Pressure to the Direction of the Wind.

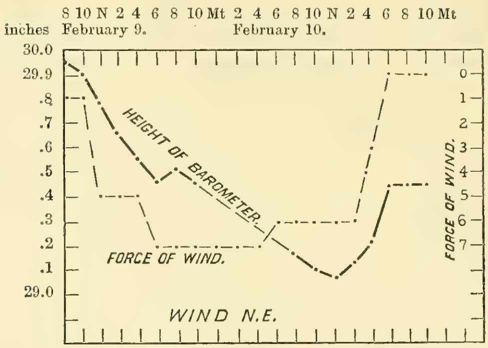
The changes of the barometric pressure, depending upon the direction of the wind, can only be investigated approximately from our observations, since the wind appears to blow principally from two directions, the number of entries from other directions being exceedingly few; besides, the series of barometric observations does not extend to a full year, and the daily observing hours are not symmetrically distributed over the twenty hours. By means of the preceding formula expressing

the annual fluctuation, the barometric height for each day was computed and subtracted from the observed height at the hours 8 A. M., noon, 4, and 10 P. M. These differences (positive for greater, negative for less pressure than the normal) were tabulated according to the direction of the wind. After balancing the resulting average effect for the directions (true) N. E. and S. W., and for calms, it appears that the barometric column is depressed about $0^{in}.07$ during N. E. wind, and elevated about $0^{in}.04$ during S. W. wind and during calms; at Van Rensselaer Harbor the depression during N. E. wind was $0^{in}.01$, and the elevation during S. W. wind $0^{in}.04$, and during calms $0^{in}.01$.[1]

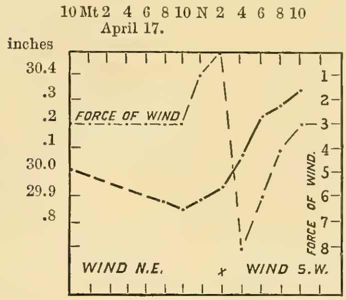
Oscillation of the Barometric Column during Storms.

There are 25 storms recorded (see discussion of winds), during one-third of which the barometer was notably affected; the range was between 0.3 and 0.9 of an inch. The readings of the barometer during the storms of November 9 and 10, 1860, of February 9, 1861, and of April 17, 1861, are illustrated by diagrams.





[1] See p. 108 of my Reduction of Captain McClintock's Meteorological Observations at Port Kennedy and Baffin Bay.



Note on Atmospheric Moisture.

An attempt was made to obtain the vapor pressure by means of hygrometric observations between February 24 and April 16; wet bulb thermometer No. 1644 (covered with a thin coating of ice) was read once or three times a day. Comparing it with No. 3, I find its index correction, from nine comparisons during snow fall, $=-1^{\circ}.8$ at the temperature -15° Fah. The observations, however, were found too rough, the greatest precision being required at these low temperatures when the relative humidity can be determined only approximately, though the numerical amount of vapor pressure (hardly exceeding $0^{in}.02$) may be well ascertained.

The dependence of the atmospheric moisture on the direction of the wind was found by means of tabulation of 128 cases of snow or rain with the direction of the wind.

During precipitation it blew 56 times from the S. W.; it was calm 45 times; and there were but 18 entries, mostly in summer, with N. E. wind; 7 with S. E., and 2 with W. wind. S. W. is therefore the rainy quarter, as might have been expected, and calms, generally, appear to favor precipitation.

WIND.

THE direction and force of the wind at Port Foulke was recorded bi-hourly together with the observations of the temperature and pressure of the atmosphere. The record, here presented, will therefore extend over eleven months.

Dr. Hayes informed me that the direction of the wind was invariably recorded with reference to the *true* meridian.

The scale of force adopted is the same as that used in the Kane expedition, viz., from 0 (calm) to 10 (hurricane) in accordance with Smeaton's table.

Denomination of wind.	Estimated number of force.	Pressure in pounds per square foot.	Velocity in st. miles per hour.
Calm	0	0.000	0
Light air	1	0.005	1
Gentle breeze	2	0.08	4
Moderate breeze	3	0.9	13
Fresh breeze	4	2.6	23
Strong breeze	5	5.1	32
Fresh gale.	6	7.9	40
Strong gale	7	12	50
Storm	8	18	60
Tempest	9	31	80
Hurricane	10	49	100

The force of the wind was estimated by the observers.

Direction (true) and force of the wind observed near and at Port Foulke.
September, 1860.

Hour	1st	2	3	4	5	6	7	8	9	10th
2 A.M.	N. E. 8	- - -	- - -	- - -	- - -	- - -	N. E. 5	- - -	- - -	- - -
4	"	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
6	"	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
8	"	N. 6	N. E. 5	E.N.E. 5	N.N.E. 7	calm	N. E. 5	N. E. 5	- - -	N. E. 5
10	"	N.byE. 6	"	N.N.E. 5	"	"	"	"	- - -	"
Noon	"	"	"	N.N.E. 7	N.N.E. 5	"	"	"	- - -	"
2	"	N.by E.--	"	"	- - -	"	"	"	- - -	N. 5
4	"	- - -	"	"	calm	"	"	N. E. 3	- - -	"
6	N. E. --	- - -	- - -	"	- - -	"	"	"	N. E. 3	"
8	N. W. 3	- - -	N.N.E.--	"	calm	"	"	"	- - -	"
10	N. W. --	- - -	"	"	"	"	"	"	- - -	N. 3
12	- - - 5	- - -	- - -	"	"	N. 5	- - -	- - -	- - -	- - -

Hour	11th	12	13	14	15	16	17	18	19	20th
2 A.M.	- - -	N. E. 3	N. E. 4	- - -	- - -	calm	N. E. 6	N. E. 4	N. E.--	N. E. 5
4	- - -	"	"	N. E. 4	N. E. 4	"	"	"	N. E. 3	"
6	- - -	- - -	"	- - -	"	"	"	"	"	"
8	calm	N. E. 4	"	- - -	"	"	N. E. 5	"	"	"
10	"	"	"	N. E. 4	"	S. W. 2	"	- - -	"	"
Noon	"	N. E. 5	"	N. E. 5	"	- - -	N. E. 6	N. E. 5	"	N. E. 3
2	"	"	"	N. E. 4	N. E. 3	S. W. 2	N. E. 4	"	N. E. 2	N. E. 2
4	"	N. E. 3	"	- - -	N. E. 2	"	"	"	N. E. 1	N. E. 3
6	"	"	"	N. E. 4	"	N. E. 2	"	"	calm	"
8	"	N. E. 4	"	"	"	"	- - -	"	"	"
10	N. E. 3	"	"	"	calm	"	N. E. 5	N. E. 4	"	"
12	calm	"	N. E. 2	"	"	N. E. 3	"	"	N. E. 2	"

Hour	21st	22	23	24	25	26	27	28	29	30th
2 A.M.	N. E. 5	S. W.--	N. E.--	N. E. 8	N. E.--	- - -	- - -	S. E. 5	N. E. 8	N. E. 8
4	N. E. 3	"	N. E. 6	"	N. E. 3	N. E.--	- - -	S. E. 3	"	"
6	- - -	- - -	- - -	- - -	"	N. E. 3	- - -	calm	"	"
8	calm	S. W. 3	N. E. 6	N. E. 6	"	"	S. E. 3	N. E. 1	- - -	"
10	"	"	N. E. 8	"	- - -	"	- - -	calm	N. E. 6	N. E. 7
Noon	"	S. W. 2	- - -	"	- - -	"	- - -	N. E. 3	N. E. 8	"
2	"	S. W. 1	N. E. 8	"	N. E. 3	"	- - -	"	"	"
4	"	calm	"	"	"	N. E. 4	S. E. 6	N. E. 5	"	"
6	S. W.--	"	"	"	- - -	- - -	"	N. E. 8	"	"
8	- - -	"	"	"	N. E. 3	- - -	- - -	"	"	"
10	- - -	N. E. 3	"	"	"	N. E. 4	- - -	"	"	"
12	S. W.--	N. E. 5	"	- -	"	calm	S. E. 6	"	"	"

September 1, 8 A. M. to 4 P. M. Wind blowing almost a hurricane; hove to under bare poles.
September 9, 8 P. M. Blowing in squalls off shore.
September 23, 10 A. M. to midnight. Blowing in squalls, and very heavy.
September 28, 8 P. M. Wind blowing in heavy squalls.
September 29, midnight. Blowing heavy.

Direction (true) and force of the wind observed at Port Foulke.
October, 1860.

Hour	1st	2	3	4	5	6	7	8	9	10th
2 A.M.	N. E. 8	N. E.--	---	W.--	calm	calm	S. W. 7	---	---	N. E.--
4	---	"	calm	---	"	"	---	---	---	"
6	N. E. 8	"	"	W.--	---	"	S. W. 7	S.--	---	---
8	"	"	"	"	N.--	"	"	"	calm	N. E. 6
10	"	N. E. 3	"	"	calm	"	"	"	"	N. E. 1
Noon	"	calm	W.--	"	"	S. W.--	"	"	"	"
2	N. E. 6	"	W. 4	"	"	S. W. 6	"	S. 8	N. E. 2	N. E. 3
4	N. E. 5	"	W. 6	"	"	"	"	S. 7	"	N. E. 1
6	"	"	"	"	"	"	"	"	"	"
8	"	"	"	"	"	"	"	"	N. E. 4	calm
10	N. E. 4	"	"	"	"	"	"	"	N. E. 5	"
12	"	"	"	"	"	S. W. 7	"	S.S.W. 5	"	S. E.--

Hour	11th	12	13	14	15	16	17	18	19	20th
2 A.M.	N. E. 1	calm	N. E.--	N. E.--	N. E.--	---	N. E.--	N. E. 4	N. E.--	N. E.--
4	N. E. 6	"	"	"	"	---	"	"	"	"
6	---	"	"	"	"	---	N. E. 1	"	"	"
8	---	"	N. E 7	N. E. 7	N. E. 6	N. E. 6	calm	"	"	"
10	calm	S. W.--	"	N. E. 6	"	"	"	"	"	"
Noon	"	calm	"	"	"	"	"	"	N. E. 8	"
2	"	"	"	"	"	"	"	"	"	"
4	"	"	N. E. 6	N. E. 5	"	"	"	"	N. E. 6	"
6	"	"	"	"	"	"	"	"	"	"
8	"	"	"	"	"	N. E. 5	"	"	"	"
10	N. E. 2	"	"	N. E. 6	"	N. E. 4	"	"	"	"
12	S. E.--	N. E.--	"	"	"	"	"	"	"	---

Hour	21st	22	23	24	25	26	27	28	29	30	31st
2 A.M.	N. E. 2	calm	N. E.--	N. E.--	N.E.--	calm	---	N.E.--	S.W.--	S.W.--	calm
4	"	"	"	"	"	N. E.--	N.--	"	"	"	"
6	N. E. 1	"	"	"	---	"	calm	"	"	"	"
8	calm	S. W.--	N. E. 4	calm	N.E.--	N. E. 1	"	calm	"	"	"
10	"	"	"	N. E. 3	N. E. 1	calm	"	S.W.--	"	"	"
Noon	"	"	"	"	calm	"	"	"	"	"	"
2	"	S. W. 1	N. E. 6	"	"	"	"	"	"	S. W. 1	N. E. 2
4	"	calm	"	"	"	"	N.W.--	"	"	calm	"
6	"	"	"	"	S. W. 2	"	"	"	"	"	N. E. 5
8	"	"	"	"	"	"	"	"	---	"	"
10	"	"	"	"	S. W. 1	"	N.E.--	"	---	"	N. E. 7
12	"	N. E.--	"	"	---	"	"	"	---	"	"

October 6, midnight. Blowing in heavy squalls.
October 7. Blowing in heavy squalls during the entire day.
October 8. Blowing in heavy squalls during the day.
October 9, 10 P. M. Blowing in squalls.
October 10, 8 A. M. Wind blowing in squalls.
October 14, 8 A. M. Blowing in heavy squalls.
October 29. Wind blowing in heavy squalls throughout the day.

Direction (true) and force of the wind observed at Port Foulke.
November, 1860.

Hour	1st	2	3	4	5	6	7	8	9	10th
2 A.M.	N. E.--	N. E.--	N. E.--	N. E.--	calm	calm	N.--	calm	N. E.--	S. W.--
4	"	"	"	"	"	"	"	"	calm	"
6	"	"	"	"	"	"	"	N. E.--	N. E.--	"
8	N. E. 8	"	"	"	N. E. 1	N. E. 3	N. E. 4	N. E. 1	N. E. 3	S. W 6
10	"	"	"	"	"	"	"	calm	"	"
Noon	"	"	"	"	"	"	N. E. 2	S. W.--	N. E. 2	S. W. 4
2	"	"	"	"	"	"	"	calm	"	S. W. 7
4	"	"	"	"	"	"	"	"	N. E. 1	"
6	"	"	"	"	calm	"	N. E. 1	"	S. W. 4	"
8	"	"	"	"	"	"	S. W. 2	N. E. 2	S. W. 7	S. W. 6
10	"	"	"	"	"	"	S. W. 4	"	S. W. 8	S. W. 4
12	"	"	"	"	"	"	---	"	"	calm

Hour	11th	12	13	14	15	16	17	18	19	20th
2 A.M.	calm	calm	calm	N. E.--	N. E.--	N. E.--	N.E.--	calm	N. E.--	N. E.--
4	"	"	"	"	"	"	"	"	"	"
6	"	"	"	"	"	"	"	N. E.--	N. E. 4	"
8	"	"	"	"	N. E. 3	N. E. 7	N. E. 2	N. E. 3	N. E. 3	N. E. 3
10	"	"	"	N. E. 7	"	"	"	"	N. E. 5	"
Noon	"	"	"	"	"	"	calm	N. E. 1	N. E. 3	N. E. 2
2	"	"	"	"	"	"	"	N. E. 3	"	N. E. 1
4	"	"	"	"	"	"	"	"	"	calm
6	"	"	"	"	"	"	"	N. E. 4	N. E. 5	"
8	"	"	"	"	"	"	"	N. E. 5	"	"
10	"	"	N. E. 2	"	"	"	"	"	"	"
12	"	"	"	"	"	---	"	---	"	"

Hour	21st	22	23	24	25	26	27	28	29	30th
2 A.M.	S. E.--	N. E.--	N. E.--	N. E.--	calm	calm	calm	S. E.--	calm	S. W.--
4	"	"	"	"	"	N. E. 1	"	"	"	"
6	calm	"	"	"	"	"	"	"	"	"
8	"	N. E. 7	N. E. 7	N. E. 6	"	N. E. 6	"	S. W. 4	"	calm
10	"	"	"	"	"	"	"	"	"	"
Noon	"	"	"	N. E. 3	"	N. E. 3	"	"	"	"
2	"	"	"	calm	"	"	"	"	N. E. 2	"
4	"	"	"	"	"	"	S. W. 2	"	"	"
6	"	"	"	"	"	"	"	"	N. E. 4	"
8	"	"	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"	"	"
12	N. E.--	"	"	"	"	S. W. 2	"	calm	---	S.W.--

Direction (true) and force of the wind observed at Port Foulke
December, 1860.

Hour	1st	2	3	4	5	6	7	8	9	10th
2 A.M.	S. W.--	S. W.--	N. E.--	calm	calm	N. E.--	N. E.--	N. E.--	N. E.--	N. E.--
4	- - -	"	"	"	N. E.--	"	"	"	"	"
6	S. W.--	"	"	"	- - -	"	"	"	"	"
8	S. W. 8	calm	N. E. 4	"	N. E. 3	N. E. 7	N. E. 7	N. E. 8	N. E. 8	N. E. 8
10	"	"	"	"	"	"	"	"	"	"
Noon	"	"	"	"	"	"	"	"	"	"
2	"	"	"	"	"	"	"	"	"	"
4	"	"	"	"	"	"	"	"	"	"
6	"	"	"	"	"	"	"	"	"	"
8	"	N. E. 2	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"	"	"
12	"	"	"	"	"	"	"	"	"	"

Hour	11th	12	13	14	15	16	17	18	19	20th
2 A.M.	N. E.--	S. E.--	N. E.--	N. E.--	S. E.--	N. E.--	N. E.--	S. W.--	S. W.--	S. W.--
4	"	- - -	"	"	N. E. 1	"	calm	"	"	"
6	"	calm	"	"	"	"	"	"	"	"
8	N. E. 7	N. E. 1	N. E. 4	N. E. 4	N. E. 4	N. E. 5	"	calm	S. W. 5	S. W. 6
10	"	"	N. E. 6	"	"	"	"	"	"	"
Noon	"	"	"	calm	"	"	"	"	S. W. 3	"
2	N. E. 3	calm	"	"	"	"	"	"	calm	"
4	calm	"	"	"	"	"	"	"	N. E. 1	"
6	S. W. 1	"	"	"	"	"	"	"	N. E. 3	"
8	"	"	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"	N. E. 1	"
12	"	- - -	"	"	"	"	"	"	S. W.--	"

Hour	21st	22	23	24	25	26	27	28	29	30	31st
2 A.M.	- - -	calm	calm	N. E.--	N. E.--	N. E.--	calm	calm	N. E.--	S. E.--	calm
4	calm	"	"	"	"	"	"	- - -	"	calm	"
6	"	"	"	- - -	"	- - -	- - -	- - -	- - -	- - -	"
8	"	"	"	N. E. 2	N. E. 4	- - -	calm	- - -	N. E.--	calm	"
10	"	"	"	"	N. E. 3	- - -	"	S. W.--	N. E. 4	"	"
Noon	"	"	"	N. E. 3	"	- - -	"	S. W. 2	"	"	"
2	"	"	- - -	"	"	S. W. 1	"	- - -	"	"	"
4	"	"	- - -	N. E. 4	- - -	calm	- - -	N. E. 3	- - -	"	N. E. 2
6	"	"	- - -	"	- - -	"	- - -	N. E. 2	- - -	"	"
8	"	"	- - -	"	- - -	"	- - -	"	calm	"	"
10	"	"	N. E. 4	"	- - -	- - -	- - -	"	"	"	"
12	"	"	S. W.--	"	- - -	calm	calm	N. E.--	"	"	"

Direction (true) and force of the wind observed at Port Foulke.
January, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2 A.M.	- - -	N. E.--	N. E.--	calm	S. W.--	calm	N. E.--	- - -	calm	N. E.--
4	- - -	"	"	"	calm	"	"	S. E. 1	N. E.--	"
6	- - -	"	calm	"	"	"	"	"	"	"
8	N. E. 4	- - -	"	"	"	"	N. E. 6	S. E. 2	N. E. 5	N. E. 6
10	"	N. E. 5	"	"	"	"	"	S. E. 3	N. E. 7	"
Noon	"	"	"	"	"	"	"	S. E. 2	"	"
2	"	"	"	"	"	"	N. E. 4	"	N. E. 6	N. E. 3
4	"	"	"	"	"	N. E. 3	N. E. 2	"	"	calm
6	"	"	"	"	N. W. 1	"	calm	N. W.--	"	"
8	"	N. E. 3	"	S. W. 1	"	N. E. 2	"	"	"	"
10	- - -	"	"	S. W. 2	"	"	"	"	"	S. W. 1
12	N. E. 4	"	"	"	N. E.--	"	"	calm	"	calm

Hour	11th	12	13	14	15	16	17	18	19	20th
2 A.M.	S. E.--	N. E.--	N. E.--	calm	calm	calm	S. W.--	calm	N. E.--	N. E.--
4	"	"	"	"	"	S. E.--	"	"	"	"
6	"	"	"	"	"	calm	- - -	- - -	"	"
8	"	N. E. 2	N. E. 7	"	"	"	calm	- - -	N. E. 6	N. E. 5
10	"	"	"	"	N. E. 1	"	"	calm	"	"
Noon	"	"	"	"	"	"	"	"	"	"
2	"	"	"	"	calm	"	"	S. E. 1	"	"
4	calm	"	"	"	"	"	"	N. E. 4	"	"
6	"	"	N. E. 4	"	"	"	"	"	"	"
8	"	"	N. E. 3	"	"	"	"	"	"	"
10	"	"	calm	"	"	"	"	"	"	"
12	N. E.--	"	"	"	N. E.--	S. W.--	"	"	"	"

Hour	21st	22	23	24	25	26	27	28	29	30	31st
2 A.M.	N.E.--	N.E.--	calm	calm	calm	N.E.--	N.E.--	S. E.--	S.W. 1	N. E.--	calm
4	"	"	"	"	"	"	"	"	S.W. 3	"	"
6	"	"	"	S. E.--	"	"	"	"	"	"	"
8	N. E. 5	N. E. 5	"	S. E. 1	"	N. E. 5	S.W. 6	E. 1	"	"	"
10	"	N. E.--	"	N. E.--	"	"	S.W. 2	"	"	E. 1	S. E. 1
Noon	"	N. E. 3	"	S. W. 2	N. E. 3	"	"	calm	"	"	"
2	N. E. 3	- - -	"	"	"	"	S. E. 2	"	"	"	"
4	"	N. E. 2	"	S. W. 1	"	"	"	"	"	S.W. 1	S.W. 1
6	"	"	"	calm	"	"	"	"	"	"	"
8	"	"	"	"	"	"	"	"	S.W. 1	"	"
10	"	"	"	"	"	"	"	"	"	"	"
12	"	"	"	"	"	"	"	"	N. E.--	N.E.--	"

January 13, 10 A. M. to 8 P. M. Wind blowing in heavy squalls.

Direction (true) and force of the wind observed at Port Foulke.
February, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2 A.M.	N. E.--	calm	N. E.--	E.--	N. E.--	- - -	calm	calm	S. W.--	N. E.-
4	"	E. - -	"	- - -	"	N. E.--	"	"	"	"
6	"	N. E.--	"	E.--	"	"	"	"	"	"
8	"	calm	- - -	N. E. 4	N. E. 3	"	"	N. E.--	N. E. 1	N. E. 6
10	N. E. 4	"	N. E.--	"	"	"	"	calm	"	"
Noon	N. E. 6	"	"	"	"	"	"	"	N. E. 5	"
2	"	S. E. 3	S. E.--	"	N. E. 2	"	"	"	"	"
4	N. E. 3	S. W.--	"	"	N. E. 1	N. E. 3	"	"	"	N. E. 3
6	calm	"	S. E. 1	"	"	"	"	"	N. E. 7	calm
8	"	"	calm	"	N. E. 3	"	"	"	"	"
10	"	"	"	"	"	"	"	"	"	"
12	"	N. E.--	S. E.--	"	"	calm	"	N. E.--	"	"

Hour	11th	12	13	14	15	16	17	18	19	20th
2 A.M.	S. W.--	S. W.--	N. E.--	N. E.--	N. E.--	N. E.--	N. E.--	S. W.--	calm	calm
4	"	"	"	"	"	"	calm	"	"	- - -
6	"	"	calm	"	"	"	"	- - -	"	N. E.--
8	S. W. 1	"	"	N. E. 6	N. E. 5	N. E. 5	"	calm	"	"
10	"	S. W. 2	"	"	"	"	"	"	"	N E. 4
Noon	"	"	"	"	"	"	"	"	"	"
2	"	"	"	"	"	"	S. W.--	"	"	"
4	"	"	"	"	"	"	calm	"	"	"
6	"	"	N. E.--	"	"	"	"	"	"	"
8	S. W. 3	"	N. E. 5	"	"	"	N. E. 1	"	"	"
10	"	"	"	"	"	"	"	"	"	"
12	"	N. E.--	"	"	"	"	"	"	"	"

Hour	21st	22	23	24	25	26	27	28th
2 A.M.	N. E.--	- - - -	calm	N. E.--	N. E.--	N.--	N.--	N. E.--
4	"	calm	"	"	- - - -	"	"	"
6	"	"	"	"	N. E.--	"	"	"
8	N. E. 3	"	"	N. E. 7	N. 7	N. 6	N. 5	N. E. 3
10	"	"	"	"	"	"	"	"
Noon	"	"	"	"	"	"	"	"
2	"	"	N. E. 3	"	"	"	"	"
4	N. E. 2	"	"	"	"	"	"	"
6	"	"	"	"	"	N. 5	"	"
8	"	"	"	"	"	"	"	"
10	"	"	"	"	N. 8	"	"	"
12	"	"	"	"	"	"	"	"

Direction (true) and force of the wind observed at Port Foulke.
March, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2 A.M.	N. E.--	S. W.--	S. W.--	N. E.--	N. E.--	N. E.--	N. E.--	N. E.--	calm	N. E.--
4	"	"	"	"	"	"	"	"	N. E.--	"
6	"	"	calm	"	"	"	"	"	"	"
8	calm	S. E. 3	S. E. 2	N. E. 3	N. E. 3	N. E. 2	N. E. 3	N. E. 4	N. E. 1	N. E. 1
10	"	"	"	"	"	"	"	"	"	"
Noon	"	"	"	"	"	"	"	"	"	"
2	"	"	S. E. 1	"	"	"	"	"	"	S. W. 1
4	"	S. E. 2	calm	"	"	"	"	"	"	S. W. 3
6	"	S. E. 1	N. E. 1	"	"	"	"	N. E. 1	N. E. 3	"
8	"	"	"	"	"	"	"	calm	"	"
10	"	"	"	"	"	"	"	"	"	"
12	S. W.--	"	"	"	---	"	"	"	"	"

Hour	11th	12	13	14	15	16	17	18	19	20th
2 A.M.	S. W.--	S. W.--	N. E.--	calm	N. E.--	calm	N. E.--	calm	calm	N. E.--
4	"	"	"	"	"	"	"	"	S. W.--	"
6	"	"	calm	"	"	"	calm	"	N. E.--	"
8	S. E. 2	"	"	"	N. E. 5	"	"	---	N. E. 1	"
10	"	S. W. 3	N. E. 1	N. E. 2	"	N. E. 1	"	N. 2	"	N. E. 3
Noon	S. E. 1	S. W. 2	calm	N. E. 5	N. E. 3	calm	"	"	"	N. E. 1
2	"	"	"	"	"	"	"	"	"	"
4	"	"	S. E. 1	"	"	"	"	"	"	S. E. 1
6	S. E. 3	S. W. 4	"	"	S. 1	"	"	"	calm	N. E. 1
8	"	"	"	"	calm	N. E. 3	"	calm	N. E. 4	calm
10	"	"	"	"	"	"	"	"	"	"
12	"	N. E.--	calm	"	"	"	"	"	"	"

Hour	21st	22	23	24	25	26	27	28	29	30	31st
2 A.M.	calm	N. E.--	calm	calm	calm	N.E.--	N.E.--	S.W.--	---	N.E.--	calm
4	"	"	"	"	S. W.--	calm	"	"	N.--	"	"
6	"	"	"	"	"	"	"	"	calm	"	N.E.--
8	"	N. E. 1	"	"	S. W. 1	"	N. E. 4	S. E. 4	"	N. E. 4	calm
10	"	calm	"	"	"	"	"	"	"	"	"
Noon	"	"	"	"	"	S.W.--	"	"	N. E.--	"	"
2	"	"	"	"	"	S.W. 3	N. E. 3	"	N. E. 4	N. E. 2	"
4	"	"	"	"	"	N. E. 1	N. 1	calm	"	N. E. 1	"
6	"	"	"	"	"	"	calm	S. E. 1	"	"	S. E. 1
8	"	"	"	"	"	"	"	"	N. E 3	calm	calm
10	N. E. 3	"	"	"	"	N. E. 5	---	"	"	"	N. E. 1
12	"	"	"	"	calm	"	S.W.--	"	---	"	calm

Direction (true) and force of the wind observed at Port Foulke.
April, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2 A.M.	calm	S. W.--	N. E.--	N. E.--	S. W. 4	S.W.--	N. E.--	N. E.--	N. E.--	N. E.--
4	"	"	"	"	"	"	"	"	"	"
6	"	"	"	"	S. E.--	"	"	"	"	"
8	"	"	"	N. E. 1	S. E. 3	S. E. 1	N. E. 3	N. E. 3	"	N. E. 3
10	"	S. W. 3	"	"	"	calm	N. E. 4	"	"	"
Noon	"	"	calm	N. E. 2	"	N. E. 1	"	"	"	"
2	S. E. 1	"	"	N. E. 4	"	"	"	"	"	"
4	S. E. 3	"	"	"	"	N. E. 3	"	"	"	"
6	S. E. 1	"	"	"	S. E. 5	"	"	"	"	"
8	S. E. 2	"	S. W. 1	"	"	N. E. 2	"	"	"	"
10	"	calm	calm	"	"	"	---	"	"	"
12	"	N. E.--	S. W.--	"	"	---	---	"	"	N. E. 6

Hour	11th	12	13	14	15	16	17	18	19	20th
2 A.M.	N. E.--	N. E.--	S. W. 1	S. W. 7	N. E. 1	N. E. 3	N. E. 3	S. W. 3	calm	calm
4	"	"	"	"	"	"	"	"	"	"
6	"	calm	S. W. 2	"	N. E. 3	"	"	calm	N. E. 2	"
8	N. E. 6	S. W. 1	"	"	"	"	"	"	"	S. W. 1
10	"	"	"	"	N. E. 4	"	"	"	N. E. 3	calm
Noon	"	"	"	S. W. 4	"	"	N. E. 1	N. E. 1	"	"
2	"	"	"	"	"	"	calm	calm	"	"
4	"	"	S. W. 4	S. W. 3	"	"	S. W. 8	"	"	"
6	"	S. W. 2	S. W. 6	calm	"	"	S. W. 6	"	"	"
8	N. E. 4	S. W. 3	"	S. E. 1	"	"	S. W. 4	"	calm	"
10	"	"	S. W. 7	"	"	"	S. W. 3	"	"	"
12	---	"	"	"	"	"	"	"	"	S. W. 1

Hour	21st	22	23	24	25	26	27	28	29	30th
2 A.M.	S. W.--	S. E.--	N. E.--	S. W.--	calm	calm	calm	N. E. 3	N. E.--	N. E. 7
4	"	S. W. 1	"	"	"	"	"	"	"	"
6	"	"	calm	"	"	"	"	"	"	"
8	S. W. 2	"	"	S. W. 2	S. W. 2	"	N. E. 1	"	N. E. 6	N. E. 2
10	"	"	"	"	S. W. 3	"	N. E. 3	"	"	"
Noon	S. W. 3	calm	"	"	"	"	"	"	"	"
2	S. W. 4	N. E. 1	"	"	"	"	"	N. E. 4	"	"
4	"	"	S. W. 1	"	"	"	"	"	"	"
6	"	"	S. W. 2	"	"	"	"	"	"	"
8	"	calm	"	"	S. W. 1	"	"	N. E. 5	"	"
10	"	N. E. 1	"	"	"	"	"	"	N. E. 7	"
12	"	"	"	"	"	"	---	"	---	"

April 5. Blowing in squalls throughout the day.
April 21. Wind blowing in heavy squalls throughout the day.

Direction (true) and force of the wind observed at Port Foulke.
May, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2 A.M.	N. E.--	N. E.--	calm	calm	S. W. 1	N. E.--	calm	S. W.--	calm	calm
4	"	"	N. E. 1	"	calm	"	"	"	"	"
6	"	"	"	"	"	"	"	calm	"	"
8	N. E. 3	N. E. 3	"	"	"	N. E. 1	"	"	"	"
10	"	"	"	"	N. E. 3	"	"	"	"	"
Noon	"	"	"	"	"	"	"	"	"	"
2	"	"	"	"	"	- - -	"	"	"	"
4	"	"	"	S. W. 1	"	calm	"	"	"	N. E. 2
6	"	"	"	"	"	S. W. 1	N. W. 1	"	"	"
8	"	N. E. 1	calm	"	"	calm	"	"	"	N. E. 3
10	"	"	"	"	"	"	"	"	"	"
12	"	calm	"	"	"	"	"	"	"	"

Hour	11th	12	13	14	15	16	17	18	19	20th
2 A.M.	N. E.--	N. E.--	calm	S. W.--	calm	S. W.--	S. W.--	N. E.--	N. E.--	N. E.--
4	"	"	"	"	"	calm	"	"	"	"
6	"	"	"	calm	"	"	"	"	"	"
8	N. E. 3	N. E. 2	- - -	"	"	"	"	N. E. 2	N. E. 3	N. E. 2
10	"	"	S. W. 1	"	"	W.--	"	"	"	"
Noon	"	"	"	"	S. W.--	"	"	"	"	"
2	"	"	"	"	S. W. 2	"	"	"	"	"
4	"	"	"	"	S. W. 4	"	S. W. 1	"	"	"
6	"	"	calm	S. W.--	"	"	N. E. 1	"	"	"
8	"	calm	"	"	"	"	"	"	"	N. E. 1
10	- - -	"	"	"	"	"	"	"	"	"
12	N. E. 3	S. W.--	S. W.--	- - -	"	"	"	"	"	"

Hour	21st	22	23	24	25	26	27	28	29	30	31st
2 A.M.	N. E.--	N. E.--	N. E.--	N. E.--	N. E.--	N.E.--	S.W.--	N.E.--	calm	N.E.--	N.E.--
4	"	"	"	"	"	"	"	"	N.E --	"	"
6	"	"	"	"	"	"	"	"	N. E. 2	"	"
8	N. E. 1	- - -	N. E. 3	N. E. 4	N. E. 2	calm	W. 1	N. E. 1	"	N. E. 3	N. E. 6
10	calm	calm	"	"	"	"	"	S.W. 1	"	"	"
Noon	"	N. E. 2	"	"	"	"	"	S.W. 3	"	"	"
2	- - -	"	"	"	"	W. 1	N.E. 1	S.W.--	N.E.--	"	"
4	S. W. 1	"	"	"	N. E. 1	"	"	"	"	N. E. 4	"
6	"	"	"	"	"	"	"	"	"	N. E. 6	"
8	N. E. 1	"	"	"	N. E. 2	"	N.E. 2	S. W. 1	N. E. 3	N. E. 7	"
10	N. E. 2	"	"	"	"	"	"	calm	N. E. 5	N.E.--	"
12	"	"	"	"	"	"	"	"	"	"	- - -

May 30, 10 P. M. Wind blowing in heavy squalls.
May 31. Wind blowing in heavy squalls all day.

Direction (true) and force of the wind observed at Port Foulke.
June, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2 A.M.	N. E.--	N. E.--	S. E.--	N. E.--	calm	N. E.--	N. E.--	N. E.--	N. E.--	N. E.--
4	"	"	N. E.--	"	N. E.--	"	"	"	"	"
6	"	"	"	"	"	"	"	"	calm	"
8	N. E. 5	N. E. 4	N. E. 3	N. E. 3	N. E. 1	N. E. 3	N. E. 4	N. E. 1	"	"
10	"	"	"	"	"	"	"	"	"	N. E. 2
Noon	"	"	"	N. E. 2	"	"	"	calm	"	"
2	"	"	"	---	"	"	"	---	"	"
4	"	"	"	calm	"	"	"	N. E. 1	"	"
6	"	"	"	"	"	"	N. E. 2	"	"	"
8	"	"	"	"	"	"	N. E. 3	"	"	"
10	"	"	"	"	"	"	"	"	"	"
12	"	"	"	"	"	"	"	"	"	"

Hour	11th	12	13	14	15	16	17	18	19	20th
2 A.M.	N. E.--	calm	S. W.--	S. W. 1	S. W.--	S. W.--	S. W.--	S. W.--	S. W.--	---
4	"	"	"	"	"	"	"	"	"	---
6	"	S. W.--	"	"	"	"	"	"	"	---
8	"	"	"	"	S. W. 2	S. W. 7	S. W. 7	S. W. 5	S. W. 5	S. W. 2
10	"	S. W. 2	calm	"	"	"	"	"	"	"
Noon	calm	"	S. W. 1	"	"	"	"	"	"	"
2	"	"	"	"	"	"	"	"	"	"
4	"	S. W. 3	"	"	"	S. W. 6	"	"	"	"
6	"	S. W. 2	"	calm	"	"	"	"	"	"
8	"	"	calm	"	"	S. W. 7	"	"	"	"
10	"	"	"	"	"	---	"	"	"	"
12	S. W.--	"	"	S. W.--	"	---	"	"	"	"

Hour	21st	22	23	24	25	26	27	28	29	30th
2 A.M.	S. W.--	calm	calm	calm	S. W.--	S. W.--	S. W.--	calm	calm	calm
4	"	"	"	"	"	"	"	N.--	"	"
6	"	"	N. E.--	"	"	"	"	calm	"	"
8	---	"	"	"	S. W. 7	S. W. 7	S. W. 5	"	"	"
10	calm	S. W. 1	N. E. 1	"	"	"	"	"	"	"
Noon	"	"	"	N. 1	"	"	"	"	"	"
2	"	"	---	---	"	"	"	"	"	"
4	"	"	S.--	S. W. 1	"	"	"	"	"	"
6	"	"	"	"	"	"	"	"	"	"
8	"	calm	calm	"	"	"	"	"	"	"
10	"	---	"	"	"	"	"	"	"	S. W. 1
12	---	S. W.--	S. W.--	S. W.--	"	"	"	"	"	"

June 16, 8 A. M. to midnight. Blowing in squalls.
June 17, 18. Blowing in heavy squalls throughout the day.
June 19. Wind blowing in squalls.

Direction (true) and force of the wind observed at and in the vicinity of Port Foulke.
July, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10	11	12th
2 A.M.	S.W.--	S.W.--	---	N.E.--	N.E.--	N.E.--	N.--	N.E.--	N.E.--	N.E.--	S.W.--	calm
4	"	"	S.W.--	S.W.--	"	"	N.E.--	"	"	"	"	S.W. 1
6	"	"	"	"	"	"	"	"	"	"	---	N.E. 1
8	"	calm	S. 1	S.W. 2	N.E. 3	N.E. 3	calm	"	N.E. 1	N.E. 6	S.W. 2	"
10	calm	"	"	"	S.W. 1	"	"	calm	"	"	"	N.E. 2
Noon	"	"	calm	"	"	N E. 1	"	N.E. 2	---	"	"	"
2	"	"	"	"	"	"	"	S.W. 1	S.W. 1	N.E.--	S.W. 1	"
4	"	"	"	S.W. 1	calm	calm	"	S.W. 2	calm	S.W. 2	calm	N.E. 1
6	S.W. 1	"	"	calm	"	"	"	calm	"	S.W. 1	"	calm
8	"	N.E. 1	"	"	"	"	N.E. 1	"	"	---	"	S.W.--
10	"	"	"	"	N.E. 2	"	N.E. 2	S.W. 1	"	---	"	---
12	"	calm	"	"	"	N.--	"	calm	N.E.--	calm	N.E.--	---

Hour	13th	14[1]	15	16	17	18	19	20	21	22	23d
2 A.M.	S.W.--	calm	calm	S.W. 6	S.W. 7	S.W. 4	S.W. 3	N. E. 1	S. W. 1	S. W. 3	N. E. 2
4	"	"	"	"	"	"	"	"	calm	S. W. 4	"
6	---	"	"	S.W. 7	"	"	"	"	S. W. 1	S. W. 2	"
8	S.W.--	"	"	"	"	"	"	"	"	"	"
10	"	---	"	"	S.W. 4	"	"	"	"	"	N. E. 1
Noon	"	S.W. 1	"	"	"	"	"	"	"	---	"
2	"	calm	S.W. 4	"	S.W. 6	S.W. 3	S.W. 1	calm	calm	S. W. 2	---
4	S. 1	"	"	"	S.W. 5	"	"	S. W. 1	"	"	calm
6	"	"	"	"	S.W. 4	"	calm	"	"	S. W. 1	"
8	calm	"	"	"	S.W. 6	S.W. 4	"	"	S. W. 1	S. W. 2	S. W. 1
10	"	"	S.W. 6	"	"	S.W. 3	"	"	"	S. W. 1	"
12	"	"	"	"	S.W. 4	"	N. E. 1	"	S. W. 3	"	"

Hour	24th	25	26	27	28	29	30	31st
2 A.M.	S. W. 1	N.N.E. 2	N. E. 1	N. E. 1	N. 1	calm	E. N. E. 1	calm
4	"	N.N.E. 1	"	"	"	"	"	"
6	"	"	calm	"	calm	"	"	W. N. W. 1
8	"	"	"	"	"	"	calm	W. N. W. 2
10	N. E. 1	calm	"	S. S. E. 3	"	"	variable	W. 1
Noon	"	"	N. E. 1	N. 1	"	"	N. W. 1	N. W. 1
2	---	"	calm	N. E. 2	"	S. S. W. 1	S. E. 1	E. S. E.--
4	N. E. 2	"	"	N. E. 1	"	calm	S. W. 2	-----
6	N. N. E. 3	"	"	W. 1	"	"	S. S. W. 2	E. by N.--
8	"	S. E. 1	N. E. 1	W.N.W. 1	"	"	S. S. W. 4	E. by N. 2
10	N. N. E. 4	"	"	calm	"	"	S. S. W. 3	E.--
12	N. N. E. 2	calm	"	"	"	variable	S. S. W. 2	"

July 10, 8 A. M. Blowing in squalls.

[1] After July 14, noon, the record is given in "sea days," or astronomical reckoning, which is here changed to civil reckoning.

Method of Reduction.

The same method of discussion will be employed here as that used for Dr. Kane's and Sir F. L. McClintock's observations.

Let $\theta_1 \quad \theta_2 \quad \theta_3 \; \ldots .$ be the angles which the direction of the wind makes with the meridian (true), reckoned round the horizon according to astronomical usage, from the south, westward to 360°, a direction corresponding to that of the rotation of the winds in the northern hemisphere; and $v_1 \quad v_2 \quad v_3 \; \ldots$ its respective velocities, which may be supposed expressed in miles per hour, and let the observations be made at equal intervals (for instance hourly). Adding up all velocity-numbers referring to the same wind during a given period (say one month), and representing these quantities by $s_1 \quad s_2 \quad s_3 \; \ldots .$ the number of miles of air transferred bodily over the place of observation by winds *from* the southward is expressed by the formula.

$$R_s = s_1 \cos \theta_1 + s_2 \cos \theta_2 + s_3 \cos \theta_3 + \text{----}$$

and for winds *from* the westward

$$R_w = s_1 \sin \theta_1 + s_2 \sin \theta_2 + s_3 \sin \theta_3 + \text{----}$$

The resulting quantity R, and the angle ψ it forms with the meridian, are found by the expressions

$$\mathrm{R} = \sqrt{R_s^2 + R_w^2} \qquad \text{and } \tan \psi = \frac{R_w}{R_s}$$

The general formulæ, in the case of eight principal directions θ, assume the following convenient form:—

$$R_s = (S—N) + (SW—NE) \sqrt{\tfrac{1}{2}} — (NW—SE) \sqrt{\tfrac{1}{2}}$$
$$R_w = (W—E) + (SW—NE) \sqrt{\tfrac{1}{2}} + (NW—SE) \sqrt{\tfrac{1}{2}}$$

where the letters *S*, *SW*, *W*, etc., represent the *sum* of all velocities expressed in miles per hour, during the given period, or the quantity of air moved in the directions *S*, *SW*, *W*, etc., respectively. R_s represents the total quantity of air transported *to* the *northward*, and R_w the same transferred *to* the *eastward*. These formulæ, for practical application, may be put in the following convenient form:—

Let $S—N = a \qquad SW—NE = c$
$\quad W—E = b \qquad NW—SE = d$

Then

$$R_s = R \cos \psi = a + 0.707\,(c—d)$$
$$R_w = R \sin \psi + b + 0.707\,(c+d)$$

Since $R_s \quad R_w \quad R$ represents the quantity of air passed over during the given period, in the direction 0° 90° ψ° respectively, we must, in order to find the average velocity for any resulting direction, divide by n or by the number of observations during that period; we then have

$$V_s = \frac{R_s}{n} \qquad V_w = \frac{R_w}{n} \qquad \text{and } V = \frac{R}{n}$$

A particle of air which has left the place of observation at the commencement of the period — of a day, for instance — will be found at its close in a direction $180° + \psi$ and at a distance of R miles, equal to a movement with an average velocity of $\frac{R}{n}$. This supposes an equal and parallel motion of all particles passing

over the locality; the length of the path described by each can be found by the summation of all the v's (for each hour) during the period.

The great variability in the direction and force of the wind demands long periods for which it may be desirable to bring out resulting values. A subdivision of the reduction into monthly periods has been found convenient.[1]

No special advantage would be gained by including more than eight directions, and in the few cases where such intermediate directions were recorded they will be referred to the nearest principal direction, and if midway between and occurring more than once, they will be referred alternately to the preceding and following direction.

Occasional omissions in the record were supplied by interpolation; it is to be regretted that so many blanks occur in the column for force of the wind.

The following table gives the sum of the velocity-numbers for each month and for each of the principal eight directions of wind; also the resulting numbers for each season of the year as deduced from bi-hourly observations by application of the preceding method.

The numbers for August were interpolated by taking the mean of the July and September numbers.

True Direct'n	1860.				1861.								Autumn.	Winter.	Spring.	Summer.	Year.
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug. inter-pol'd.					
S.	0	564	0	0	0	0	1	0	0	1	33	16	564	0	1	50	615
N.	995	2	3	0	0	1342	21	0	0	2	4	500	1000	1342	21	507	2870
W.	0	380	0	0	0	0	1	0	17	0	5	2	380	0	18	6	404
E.	64	0	0	0	5	4	0	0	0	0	21	42	64	9	0	63	136
S. W.	57	1476	893	1150	187	103	214	1176	181	3652	1705	881	2426	1440	1571	6238	11675
N. E.	7452	4425	5229	5476	3671	3750	1989	2884	2368	1300	394	3923	17106	12897	7241	5617	42861
N. W.	148	3	0	0	6	0	0	0	4	0	6	77	151	6	4	83	244
S. E.	310	2	5	3	82	17	238	226	0	1	11	161	317	102	464	173	1056

Quantity of air passed over the place of observation, during a year, 59861 miles; at Van Rensselaer Harbor 12759, Baffin Bay 62993, and Port Kennedy 68103.

Applying the formulæ for reduction to these numbers, they give the resulting quantity of air, R, passed over during the period, and its direction ψ.

[1] A full illustration and example of the method of reduction will be found on page 63 of my reduction of Captain McClintock's Meteorological Observations. Smithsonian Contributions to Knowledge, 1862.

	R	ψ	Resulting true direction.
September	8158	222°	N. E. ¼ N.
October	2286	228	N. E. ¼ E.
November	4338	225	N. E.
December	4325	225	N. E.
January	3488	226	N. E.
February	4691	214	N. E. by N.
March	1802	232	N. E. ½ E.
April	1723	233	N. E. ¾ E.
May	2174	225	N. E.
June	2351	45	S. W.
July	1319	43	S. W. ¼ S.
August	3420	215	N. E. by N.
Autumn	14769	224	N. E.
Winter	12439	221	N. E. ¼ N.
Spring	5687	229	N. E. ¼ E.
Summer	321	82	W. ¾ S.
Year	32600	223	N. E.

The resulting direction of the wind at Port Foulke during the period of one year is from the N. E. (true), which agrees with the general movement of the atmosphere in the Arctic regions as made out by Prof. J. H. Coffin;[1] the resulting directions at Van Rensselaer[2] S. S. W. nearly, and in Baffin Bay (latitude 72°.5, longitude 65°.8) N. W. by N. do not agree with this deduction, but whether this is owing to anomalous local influences, or whether it points to a modification of the law can only be settled when a greater number of observations will have been discussed, at present it appears most likely due to local circumstances.

Relative Frequency of each Wind and of Calms.

The following table of numbers of relative frequency contains the number of entries, n, of each wind and of calms.

True direction.	1860.				1861.								Autumn.	Winter.	Spring.	Summer.	Year.
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug. interpolated.					
S.	0	12	0	0	0	0	1	0	0	1	6	3	12	0	1	10	23
N.	28	2	3	0	0	33	6	0	0	2	5	16	33	33	6	23	95
W.	0	19	0	0	0	0	1	0	17	0	4	2	19	0	18	6	43
E.	2	0	0	0	5	4	0	0	0	0	15	9	2	9	0	24	35
S. W.	15	58	37	45	34	34	41	97	46	155	130	72	110	113	184	357	764
N. E.	249	171	199	189	166	170	163	177	215	110	83	166	619	525	555	359	2058
N. W.	5	3	0	0	6	0	0	0	4	0	6	5	8	6	4	11	29
S. E.	13	2	5	3	31	5	36	21	0	1	5	9	20	39	57	15	131
Calms	48	105	116	135	130	90	124	65	90	91	118	90	269	355	279	299	1202

[1] Twelfth meeting of the Am. Association, Baltimore, 1858.

[2] See note on page 66 of Captain McClintock's Meteorological Discussions, explaining the change from magnetic to true direction at this harbor.

If we double the numbers in each column, we find the number of hours during which each wind blew, or during which it was calm, for each period. The prevailing wind is the N. E., next to it the S. W., while the relative frequency of the calms is between the two; all other winds are about equally unfrequent. Expressed in percentage the frequency of the N. E. is 47, of calms 27, of S. W. 17, and for the six remaining directions on the average 1½.

Table of comparison of relative frequency of winds and calms.

True direction.	Port Foulke.	Van Rensselaer.	Baffin Bay.	Port Kennedy.
S.	23	410	243	44
S. W.	764	354	345	159
W.	43	116	426	488
N. W.	29	330	1233	1670
N.	95	144	520	121
N. E.	2058	27	456	1104
E.	35	56	299	108
S. E.	131	411	503	114
Calms	1202	2532	341	561

This table exhibits the extreme variations in the frequency of the winds at different localities and in different years; at Van Rensselaer Harbor, with a northwest exposure, the N. E. wind is least frequent; at Port Foulke, with a west exposure, it is the most frequent wind. At the latter place the number of hours of calms is half that noted at the former place.

Average Velocity of the Wind.

The average velocity of each of the eight principal winds for each season and year is found by dividing the sum of the velocity numbers by n, or the number of entries during the period; the velocity is expressed in miles per hour.

True direction.	Velocity.
S.	27^{m}
S. W.	15
W.	9
N. W.	8
N.	30
N. E.	21
E.	4
S. E.	8

Average velocity of all winds throughout the year 19 miles per hour, producing a moderately fresh breeze. The average velocity of the air, taking also the number of calms into consideration, is 14 miles per hour. At Van Rensselaer Harbor the average velocity of all winds was 7, in Baffin Bay 17, and at Port Kennedy 18 miles per hour. These numbers are not strictly comparable, since the velocity of the wind at each locality depends upon estimation.

The velocities of the N. E. and S. W. winds alone are tolerably well ascertained, there being too few entries of other winds.

With respect to the application of the law of rotation of winds to this locality, the record, containing mostly N. E. and S. W. directions with many calms, does not appear to be sufficiently well suited to give value to any result that might be deduced.

Occurrence and Duration of Storms.

In the following list all storms are included during which the force of wind reached the conventional numbers 7 and 8.

Date.			Duration.	Direction.	Remarks.
1860.	September	1	16^h	N. E.	
	"	4, 5	24	N. N. E.	
	"	23, 24	20	N. E.	Barometer fell about $0^{in}.55$.
	"	28, 29, 30, 1	68	N. E.	
	October	6, 7, 8	48	S. W.	
	"	13, 14	16	N. E.	Barometer fell about $0^{in}.4$.
	"	19	4	N. E.	
	"	31, 1	28	N. E.	
	November	9, 10	18	N. E. and S. W.	Barometer strongly affected; mercury rose $0^{in}.85$ after the gale.
	"	14	16	N. E.	Barometer fell slowly.
	"	16	16	N. E.	Barometer fell gradually and slowly.
	"	22, 23	42	N. E.	
	December	1	18	S. W.	
	"	6, 7, 8, 9, 10, 11	126	N. E.	
	January	9	4	N. E.	Barometer fell about $0^{in}.3$.
	"	13	10	N. E.	Barometer fell about $0^{in}.45$.
	February	9	8	N. E.	Barometer fell about $0^{in}.85$.
	"	24, 25	42	N. E. and N.	Barometer slightly affected.
	April	13, 14	14	S. W.	
	"	17	2	N. E. and S. W.	Barometer rose $0^{in}.5$ after the gale.
	"	29, 30	10	N. E.	Barometer fell about $0^{in}.5$.
	May	30	2	N. E.	
	June	16, 17	38	S. W.	Barometer but little affected.
	"	25, 16	42	S. W.	
	July	16, 17	28	S. W.	

Of these 25 storms, which were recorded during 11 months, 19 came from the N. E., and 6 from the S. W.; their average duration was 26 hours. During more than one-half of these storms the barometer was not or very slightly affected. The storms appear more frequent in winter than in summer. None of the gales noted can be classed among the rotatory storms, excepting that of November 8 and 9, 1860, and that of April 17, 1861; during these two storms the wind shifted from N. E. to S. W., with an interval of calm in the latter case.

APPENDIX.

RECORD OF THE WEATHER AND MISCELLANEOUS NOTES.

Record of the weather kept on board the schooner "United States," and at Port Foulke, North Greenland, between July 11, 1860, and October 9, 1861.

The state of the weather is indicated by the following letters[1] (Beaufort's notation):—

b	blue sky.	*p*	passing showers.
c	clouds (detached).	*q*	squally.
d	drizzling rain.	*r*	rain.
f	foggy.	*s*	snow.
g	gloomy.	*t*	thunder.
h	hail.	*u*	ugly (threatening) appearance.
l	lightning.	*v*	visibility, objects at a distance unusually visible.
m	misty (hazy).	*w*	wet (dew).
o	overcast.	*z*	snow-drift.

A bar (—) or a dot (.) under any letter augments its signification.

In the following record the date adopted is that in accordance with civil reckoning; on the voyage out and on the home trip astronomical reckoning is used in the log-book, which has been changed accordingly.

[1] Beaufort's notation is not employed in the records of the expedition, but the state of the weather is described in full.

Left Boston Bay 5½ A. M. July 10, 1860.

	July 11, 1860.					July 12.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.
2	variable	--	--	--	q r	W. 3	$29^{in}.85$	63°	55°.0	b
4	"	--	--	--	"	"	--	--	--	"
6	"	--	--	--	b	"	.90	61	54.4	"
8	"	--	--	--	"	N. W. 3	.90	62	54.4	"
10	N.	--	--	--	c	"	--	--	--	"
Noon	N. 3	--	--	--	"	"	.90	61	68.0	"
2	W. 3	$29^{in}.75$	67°	64°	"	W. 2	30.00	63	55.0	"
4	"	.75	65	63	"	"	29.95	62	59	"
6	"	30.10	63	58.5	"	"	.95	62	54	"
8	"	.10	63	56.5	"	"	.90	58	54	"
10	"	--	--	56.5	"	"	.93	57	52	"
12	"	29.80	63	56	"	"	.95	57	53	c

At noon φ=42° 24′ λ=68° 05′ by obs'n.
42 29 68 24 by Dead reck.
Temp. water 56°.2; W. var'n ¾ pt.

At noon 42° 36′ 65° 32′ by obs'n.
42 38 65 25 D. R.
T. W. 53°.5; W. V. ¾ pt.

Thermometer No. 7 was used to indicate the temperature of the air.

Thermometer No. 9 was used for temp. of water, the mean of all obser's during 24 hours is given.

	July 13.					July 14.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.
2	W. 3	--	--	--	c	E. N. E. 3	29.95	62	53	r
4	"	30.10	56	52	"	N. E. 3	--	--	--	"
6	"	--	--	--	"	"	30.00	60	53	o
8	"	.15	63	56.5	m	"	29.85	59	54.5	"
10	"	--	--	--	"	E. N. E. 2	30.00	60	55	c
Noon	"	29.80	62	55	"	"	.00	60	54	b
2	S. 2	30.00	62	55.5	"	var. 1	.00	64	68	--
4	"	.00	63.5	55	o	"	.05	66	67	--
6	"	29.90	60	55	"	calm	.05	63	66	--
8	S. E. 3	.95	60.5	56	r	W.	--	--	--	--
10	"	.95	63.5	54	"	"	.10	62	60	--
12	E. S. E. 3	.95	62	53	"	"	--	--	--	--

At noon 43° 00′ 63° 50′ by obs'n.
42 57 63 57 D. R.
Temp. water 55°.0; W. var'n 1 pt.

At noon 43° 18′ 63° 00′ by obs'n.
43 07 62 35 D. R.
T. W. 56°.9; W. var. 1 pt.

	July 15.					July 16.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.
2	calm	30.10	61.5	55	--	E. N. E. 1	30.00	60	54	o
4	S.	.10	61.5	56	--	"	--	--	--	r
6	"	.10	62	56	--	"	29.90	60	55	"
8	"	.10	62	57	--	"	--	--	--	c
10	"	--	--	--	--	"	--	--	--	"
Noon	"	--	--	--	--	"	--	--	--	--
2	E. S. E.	--	--	--	m	W.S.W. 2	.93	65	64	b
4	E. N. E. 1	.10	62	56	"	"	.85	65	65	"
6	"	--	--	--	"	W.S.W. 3	.85	64	65	"
8	"	--	--	--	o	"	.80	63	57	"
10	"	--	--	--	"	"	.75	60	55.5	m
12	"	--	--	--	"	W.S.W. 4	--	--	--	"

At noon 43° 42′ 62° 17′ by obs'n.
43 35 62 15 D. R.
Temp. W. 56°.6; W. var. 1½ pts.

At noon 43° 53′ 61° 38′ by obs'n.
43 57 61 29 D. R.
T. W. 57°.1; W. var. 1½ pts.

	July 17.					July 18.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	W.S.W. 4	$29^{\text{in}}.80$	64°	52°.5	*m*	- - -	- -	- -	- -	*m*	
4	W.S.W. 5	.85	64	53	"	- - -	- -	- -	- -	"	
6	"	.75	64	53	"	- - -	- -	- -	- -	"	
8	"	.70	65	55	"	- - -	$29^{\text{in}}.90$	64°	55°	"	
10	"	.70	62	58	"	- - -	.80	64	54	"	
Noon	"	- -	- -	- -	"	- - -	.75	62	54	"	
2	"	.85	64	57	*c*	calm	30.00	66	58	"	
4	"	.85	63	57	"	"	.00	65	- -	"	
6	"	.80	63	56	"	"	.10	65	60	"	
8	"	.80	63	55	*m*	"	.20	62	57	"	
10	W.S.W. 4	.80	63	54	"	S. S. E. 1	.25	62	53	"	
12	W.S.W. 1	.90	63	55	"	S. S. E. 2	.25	63	52	"	

July 17: At noon 45° 2′ 58° 26′ by obs'n.
45 11 58 19 D. R.
T. W. 53°.1; W. var. $1\frac{3}{4}$ pts.

July 18: At noon 45° 26′ 56° 47′ D. R.
T. W. 53°.4.

	July 19.					July 20.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	S. S. E. 2	30.20	62	52	*m*	S. S. W. 5	30.00	65	50	*f*	July 19, 7 A. M., sounding 27 fath'ms, coarse gravel; at noon 40 fathoms, broken shells.
4	"	.20	61	51	"	"	- -	- -	- -	"	
6	"	.20	59.5	51	"	"	.00	58	52	"	
8	S. S. E. 3	.25	59	50.5	"	"	29.90	59	53		
10	S. S. E. 4	.20	59	50.5	"	"	.90	60	53	*f r*	
Noon	"	.30	72	51.5	"	"	.95	60	53	"	
2	S. S. W. 2	.10	67.5	53	*f*	S. S. W. 4	.95	60	53	"	July 20, 8 A. M.; dense fog; made the land about St. Shots, 40 yards ahead.
4	S. S. W. 1	.00	63	53	"	"	.75	63	53	*c*	
6	calm	29.90	60.5	51	"	"	.80	64	54	*f*	
8	S. S. W. 1	.90	61.5	51	"	"	.80	64	54	"	
10	"	.95	62	50	"	"	.75	64	54	*f r q*	
12	S. S. W. 3	30.10	62	49	"	"	.80	63	53	"	

July 19: At noon 45° 45′ 55° 54′ by D. R.
T. W. 51°.8; W. var. $2\frac{1}{4}$ pts.

July 20: At noon 46° 38′ 53° 50′ by land fall.
46 21 54 08 D. R.
T. W. 48°.3; W. var. $2\frac{1}{4}$ pts.

	July 21.					July 22.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	S. S. W. 4	- -	- -	- -	*r q*	S. W. 6	29.85	58	51	*f u q*	July 22, 8 P. M., variation 3 pt. W. by sun.
4	"	29.80	62	53.5	*r*	"	.80	58	51.5	"	
6	"	.85	61	54	"	"	- -	- -	- -	"	
8	"	.90	61	- -	*f q*	"	.34	57	52	"	
10	"	- -	- -	- -	"	"	.35	56	51	"	
Noon	"	- -	- -	- -	*f*	"	.45	58	51.5	"	
2	S. W. 5	.95	69	53	*f u q*	"	.30	56	52	*b*	
4	"	.80	64	53	"	"	.35	57	52	"	
6	"	.90	64	52	"	N. W. 4	.40	56	50	"	
8	S. W. 6	.80	63	53	"	"	.34	57	47	"	
10	"	.80	63	52	"	"	.30	57	47	"	
12	"	.80	60	52	"	"	.50	55	46	"	

July 21: At noon 47° 13′ 51° 20′ by D. R.
T. W. 50°.0; W. var. $2\frac{1}{2}$ pts.

July 22: At noon 50° 24′ 50° 55′ by D. R.
T. W. 49°.0; W. var. 3 pts.

	July 23.					July 24.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	W.S.W. 5	$29^{in}.50$	54°	45°	*b*	W.S.W. 6	- -	- -	- -	*b*	July 23, 8 P. M. saw first iceberg to the westward.
4	W.S.W. 6	- -	- -	- -	"	"	- -	- -	- -	"	
6	"	.75	56	45	"	"	- -	- -	- -	"	
8	"	.80	58	46	"	"	$29^{in}.85$	52°	48°	"	
10	"	.80	60	46	"	"	.80	51	48	- -	
Noon	"	.80	69	46	"	"	.80	54	48	- -	
2	W.S.W. 5	- -	- -	- -	"	S. W. 5	.60	55	48	*c*	
4	"	- -	- -	- -	"	"	.50	55	48	*r h*	
6	"	.80	60	48	"	"	.40	53	47	"	
8	"	.80	60	47	"	"	.35	46	43	- -	
10	"	.80	59	46.5	"	"	- -	- -	- -	- -	
12	"	- -	- -	- -	"	N. W. 7	- -	- -	- -	- -	

July 23. At noon 52° 0′ 50° 42′ by obs'n.
52 49 51 07 D. R.
T. W. 42°.6.

July 24. At noon 54° 23′ 51° 17′ by obs'n.
54 26 51 10 D. R.
T. W. 42°.9; W. var. 3¾ pts.

	July 25.					July 26.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	N. W. 8				- -	W.S.W. 3	29.70	54	45	*r*	
4	N. W. 7				- -	"	.65	54	45	*b*	
6	N. W. 6				- -	W.S.W. 4	- -	- -	- -	"	
8	N. W. 5	29.40	67	46	*c*	"	.60	53	46	"	
10	"	.50	68	46	"	"	.65	60	46	"	
Noon	"	- -	- -	- -	- -	"	.70	69	47	"	
2	S. W. 4	.70	75	48	*b*	S. W. 3	.75	58	43	"	
4	"	.75	81	51	"	S. W. 4	.65	58	43	*c*	
6	"	.70	58	52	"	S. W. 5	.60	58	46	"	
8	W.S.W. 4	.60	56	49	*c*	"	.70	55	46	"	
10	"	.70	55	46	"	"	.75	52	44	"	
12	W.S.W. 3	.70	54	45	"	"	.70	54	43	"	

July 25. At noon 56° 48′ 51° 56′ by obs'n.
56 31 51 43 D. R.
T. W. 44°.1; W. var. 3¾ pts.

July 26. At noon 59° 02′ 52° 23′ by obs'n.
59 02 52 21 D. R.
T. W. 44°.0; W. var. 4½ pts.

	July 27.					July 28.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	S. W. 6	- -	- -	43	*c*	- - -	- -	- -	42	*c*	July 28, 9 P. M. saw a fog-bow.
4	"	- -	- -	43	"	- - -	- -	- -	43	"	
6	S. W. 7	- -	- -	45.5	"	- - -	- -	- -	41	*m*	
8	S. W. 8	- -	- -	45	"	- - -	- -	- -	41	"	
10	S. W. 7	- -	- -	45.5	"	- - -	- -	- -	- -	*c*	
Noon	S. W. 7	- -	- -	45	"	- - -	- -	- -	- -	"	
2	W. S. W.	29.40	70	45.5	"	S. W. 2	29.80	50	44	"	
4	- - -	.45	70	43	"	- - -	.80	49	46	"	
6	- - -	.50	65	42	"	- - -	.80	49	45	"	
8	- - -	- -	- -	43	"	- - -	.85	45	43	*m*	
10	- - -	- -	- -	43.5	"	W. 2	.85	42	42	"	
12	- - -	- -	- -	44	"	- - -	- -	- -	- -	"	

July 27. At noon 61° 41′ 52° 39′ by D. R.
T. W. 42°.0; W. var. 5 pts.

July 28. At noon 62° 28′ 52° 38′ by obs'n.
62 52 52 37 D. R.
T. W. 41°.4; W. var. 5 pts.

	July 29.					July 30.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	- - -	- -	- -	37°	*m*	S. S. W. 8	$29^{in}.35$	63°	34°	*r*
4	W. 1	- -	- -	37.5	"	"	.30	64	34	"
6	- - -	- -	- -	35.5	"	S. S. W. 6	- -	- -	- -	"
8	- - -	$29^{in}.75$	53°	36.5	"	S. S. W. 5	.40	68	37	*m*
10	- - -	.70	51	36.5	"	S. S. W. 3	.40	55	37	*c*
Noon	- - -	.60	42	37	"	"	.30	57	38	*b*
2	S. 1	.50	60	36	"	W.S.W. 4	.50	58	42	*m*
4	S. 2	.50	60	36	"	- - -	.45	55	40	"
6	S. 3	.50	66	35	"	- - -	.50	70	38	"
8	S. 4	.55	66	35	"	- - -	.55	70	37	*c*
10	"	.55	65	35	*r*	- - -	.55	50	38	*b*
12	S. 6	.40	63	35	"	- - -	.55	50	38	"

July 29, 10 A. M. Passed an iceberg towards S. E., distant 1½ mile.
6 P. M. Saw a fog bow, colors of the spectrum easily distinguished; passed several icebergs.

July 29. At noon 63° 35′ 53° 00 by obs'n.
63 31 52 45 D. R.
T. W. 34°.6; W. var. 5¼ pts.

July 30. At noon 65° 38′ 55° 00′ by obs'n.
65 16 54 34 D. R.
T. W. 39°.0; W. var. 5½ pts.

	July 31.					Aug. 1.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	- - -	29.60	50	39	*m*	W.S.W. 4	- -	- -	38	*h*
4	- - -	.60	50	39	"	"	- -	- -	37	"
6	- - -	.55	63	39	"	W.S.W. 5	- -	- -	37	*f*
8	- - -	.50	60	39	"	"	29.50	60	37	"
10	W.S.W. 3	.40	60	39	"	W.S.W. 6	.40	60	35	*m*
Noon	"	.50	58	39	"	W.S.W. 5	- -	- -	37	"
2	"	.30	65	37	*h r*	W.S.W. 4	.80	65	41	*c*
4	"	.40	67	38	"	W.S.W. 2	.75	- -	40	"
6	"	.50	68	37	"	W.S.W. 1	.80	- -	38	"
8	"	- -	- -	36	"	"	.80	- -	37	"
10	"	- -	- -	- -	"	"	.90	- -	36	"
12	"	- -	- -	38.5	*h*	"	.90	- -	36	"

July 31, 9 A. M. Saw several whales; at 10 P. M., saw southern shore of Disco Island.

Aug. 1, 10 A. M. Off west coast of Disco opposite Nord Fiord.

July 31. At noon 68° 4′ 55° 25′ by obs'n.
68 1 55 4 D. R.
T. W. 37°.7; W. var. 6½ pts.

Aug. 1. At noon 70° 10′ 54° 57′ by obs'n.
70 07 54 58 D. R.
T. W. 37°.0.

	Aug. 2.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	calm	- -	- -	- -	*c*
4	"	- -	- -	- -	"
6	"	29.90	70	38	"
8	"	.95	70	38	"
10	W.S.W. 2	30.00	70	39	"
Noon	W.S.W. 1	.00	55	38	"
2	calm and	- -	- -	- -	- -
4	light	- -	- -	- -	- -
6	winds	- -	- -	- -	- -
8	"	- -	- -	- -	- -
10	"	- -	- -	- -	- -
12	"	- -	- -	- -	- -

Aug. 2, 6 A. M. A great number of icebergs coming out of Omenak Fiord to the E. and N.
P. M. Stood along the coast off Swartehook peninsula.

Aug. 2. At noon 71° 17′.5 by obs'n.
71 01 55° 10′ D. R
T. W. 36°.8; W. var. 7 pts.

August 3. Off Swarte-hook; calm and light airs.

August 4. Near Kingatak Island; calm and light airs.

August 5, noon. Light breeze from N. W.; took pilot on board, and entered Pröven at midnight.

August 12, 4 A. M. Got under way; towed out of harbor. At 7 A. M. the carpenter found dead in his bunk. Wind N. W. (true), force 1 to 4 between 4 and noon; force 4 to 3 between noon and midnight. 6 P. M. Passed between the outer islands and sighted Upernavik Island. At 8 P. M. took pilot on board, and entered Danish Harbor at 10 P. M. Buried the body of the carpenter, the Danish priest officiating.

August 16, noon to 5 P. M.. N. N. E. wind, force 2 to 1; calm till 9 A. M. of the 17th. Got under way at 4½ P. M.; at 5 dropped anchor on account of southerly current.

August 17. Got under way at 7 A. M., with a light northerly air. Calm from 4 P. M. till noon next day.

August 18, 19. Calm. Most of the time at anchor west of Kingitok Island. On the morning of

August 20, commenced warping from iceberg to iceberg; towed the vessel for 4 miles; at 2 P. M. a N. W. wind rose; beat between the islands up to Tessusak.

August 21, 7 A. M. Reached Tessusak Harbor; moored vessel at the mouth of Little Harbor.

August 22. Got under way at 4 P. M.

August 23. At 4 A. M. abreast of Horses Head, distant 5 miles. Wind S. W., force 4 between 4 A. M. and noon. At noon 8 miles west of Devil's Thumb; wind S. W. and W., force 4 to 2 between noon and midnight.

	August 24.					August 25.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.
2	W. 1	29in.90	45°	32°	- -	N.N.E. 3	- -	- -	- -	- -
4	S. W. 1	- -	- -	- -	- -	"	- -	- -	- -	- -
6	S. W. 3	- -	- -	- -	- -	"	30in.00	38°	27°	- -
8	W.S.W. 3	.90	45	32	*b*	"	.10	54	30	*o*
10	W. 3	30.00	65	31.5	"	"	.10	53	31	*c m*
Noon	"	.00	63	32	*c*	"	.20	54	30	"
2	"	.00	67	31.5	*s*	N.N.E. 2	.10	55	29	"
4	"	.00	61	31.5	*b*	S. E. 3	.10	70	28.5	"
6	N.N.W. 4	.00	63	31.5	"	S. E. 5	.10	- -	29.5	"
8	N. 3	.00	63	32	"	S. E. 7	.00	55	30	"
10	"	.00	63	30	"	S. E. 8	29.80	49	30	"
12	"	.00	63	28	- -	"	- -	- -	- -	- -

At noon 75° 22′ 60° 40′ by obs'n.
75 32 60 18 D. R.
T. W. 34°.0.

At noon 75° 53′ 67° 39′ by D. R.
T. W. 32°.4.

Aug. 24. Much ice in sight. 6 P. M. Cape Walker bears N. E. by E., and the Peaked Hill N. by W.

Aug. 25, noon. Sailing through small pieces of floe ice towards Cape York; hove to close under it; sent boat ashore and brought off Hans and family. At 6 P. M. got under way; stood close along the land, sailing through small pieces of floe ice.

	August 26.					August 27.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.
2	S. E. 8	- -	- -	- -	- -	S. E. 2	- -	- -	- -	- -
4	"	- -	- -	30	- -	"	- -	- -	- -	- -
6	S. E. 7	29.70	46	31	- -	N.N.E. 1	- -	- -	- -	- -
8	"	.70	46	31	*h*	N.N.E. 3	29.80	53	30	*c*
10	S. E. 6	.70	50	31	*s m*	"	.80	60	30	*s*
Noon	"	.70	49	32.5	"	N.N.E. 1	.80	60	32	*b*
2	S. E. 5	.70	49	31	"	calm	.80	60	31	"
4	S. E. 4	.70	45	31	*s*	"	.80	58	31	"
6	S. E. 2	.70	43	31	"	"	.80	53	31	"
8	"	.80	63	31	"	N. E. 8	.80	60	30	- -
10	"	.80	75	32	"	"	.80	58	28	- -
12	"	- -	- -	- -	- -	"	- -	- -	- -	- -

Temp. W. 32°.1

Temp. W. 32°.8.

Aug. 26, 2 A. M. Passed Wolstenholm Island; passed Cape Perry at 9 A. M. Wind moderated; thick, with snow storm. 2 P.M. Passed Hakluyt Island; wind heavy; snow storm; no land in sight; pack to the north.

Aug. 27, 7 A. M. Cleared off, heading towards the land north of Cape Saumarez, distant 12 miles. Tacked ship, stood along the land; Cape Alexander and Sutherland Island in sight. 3 P. M. Towed the ship towards Cape Alexander. 7 P. M. A heavy gale from N. E. sprung up suddenly; hove to near pack at 10 P. M.

	August 28.					August 29.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	N. E. 8	- -	- -	- -	- -	N. E. 8	- -	- -	- -	- -	Aug. 28, 4 P. M. Hove to 3 miles to southward of Sutherland Island. Much trouble in clearing numerous icebergs. Aug. 29. At noon half way between Cape Saumarez and Sutherland Island.
4	"	- -	- -	- -	- -	"	- -	- -	- -	- -	
6	"	- -	- -	- -	*b*	"	- -	- -	- -	- -	
8	"	$29^{in}.70$	58°	31°	"	N. E. 7	$29^{in}.70$	62°	32°	- -	
10	"	.70	48	31	"	N. E. 6	.60	56	33	*b*	
Noon	"	.80	60	31	"	N. E. 7	.60	60	32.5	"	
2	"	.80	65	31	"	squally	.60	54	31	"	
4	"	.80	63	30	"	from calms	.60	70	32	"	
6	"	.80	60	28	"	to heavy	.60	64	30	"	
8	"	.70	61	28	"	gales	.60	70	32	- -	
10	"	.70	61	28	- -		.60	65	31	- -	
12	"				- -		- -	- -	- -	- -	
	T. W. 32°.7.					T. W. 32°.9.					

	August 30.					August 31.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	squally	- -	- -	- -	- -	N. E. 8	- -	- -	- -	- -	Aug. 30, 3½ A. M. Dropped anchor in 4 fathoms north end of Little Bay N. of Cape Saumarez. Aug. 31, 2 A. M. Vessel commenced dragging her anchor; got under way; rounded Cape Alexander at 6½ A. M.; made the pack at 10 A.M., about 14 miles N. W. by W. from the Cape, stood for Crystal Palace Cliffs.
4	"	- -	- -	- -	- -	"	29.70	- -	26	- -	
6	"	- -	- -	- -	- -	N. E. 7		- -	- -	- -	
8	"	29.70	55	30	- -	"	.75	57	23.5	- -	
10	"	.70	63	30	- -	"	.80	63	23.5	*b c*	
Noon	"	.70	65	30	- -	"	.80	65	23.5	*b*	
2	N. E. 2	.70	61	30	- -	"	.80	67	24	"	
4	N. E. 3	.70	60	31	- -	"	.80	70	24.5	"	
6	N. E. 6	.70	50	31	- -	"	.80	62	24	"	
8	N. E. 8	.70	- -	29	- -	"	.80	69	24	"	
10	"	.70	- -	27.5	- -	"	.80	69	24	"	
12	"	- -	- -		- -	- - -			19	- -	
	T. W. 33°.0.					T. W. 31°.0.					

Record of the weather during September, 1860.

Hour	1st	2	3	4	5	6	7	8	9	10th
2	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
4	b c	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
6	"	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
8	"	m	- - -	b	- - -	- - -	b	- - -	- - -	b
10	"	"	- - -	- - -	- - -	- - -	"	- - -	- - -	"
Noon	"	"	- - -	- - -	- - -	f	"	- - -	- - -	"
2	"	b m	- - -	- - -	- - -	f s	"	- - -	- - -	"
4	"	- - -	- - -	- - -	- - -	"	"	- - -	- - -	"
6	b	- - -	- - -	- - -	- - -	"	"	- - -	b c	"
8	"	- - -	- - -	- - -	- - -	"	"	- - -	b q	"
10	b m	- - -	- - -	- - -	- - -	- - -	"	- - -	- - -	b c
12	"	- - -	- - -	b m	- - -	- - -	- - -	- - -	- - -	- - -
Temp. of water.	29°.0	29°.0	29°.0	29°.0	29°.0	30°.0	30°.0	30°.0	30°.0	30°.0
Hour	11th	12	13	14	15	16	17	18	19	20th
2	- - -	o	b	- - -	- - -	- - -	c	b	b	b
4	- - -	"	b q	- - -	b	o	o	"	"	"
6	s m	"	"	- - -	"	"	o q	"	"	"
8	"	b c	"	- - -	"	"	b c	b m r q	"	"
10	"	"	"	b c q	b c	c	b	"	"	"
Noon	"	b c q	"	"	"	"	"	o	"	"
2	"	"	"	b q	"	"	"	b c	"	"
4	"	b c	"	"	"	"	"	"	"	"
6	o	"	"	"	b	"	"	b	"	b c f
8	"	"	"	b m	o	"	"	"	"	o
10	"	"	b	b	m	"	"	"	"	"
12	"	"	"	b m	"	"	"	b m	"	"
Hour	21st	22	23	24	25*	26	27	28	29	30th
2	c	o	c	b q	o	- - -	- - -	s	b	b
4	o	"	"	"	"	o	- - -	"	"	"
6	"	"	"	"	b	"	- - -	b	"	"
8	s	c q	c m	"	- - -	"	s	o	"	b m
10	"	o	b q	"	- - -	"	- - -	o z	o	"
Noon	o	b c	"	o	- - -	"	- - -	"	"	b
2	"	"	"	"	b	"	- - -	"	b m	"
4	"	b	"	b c	o	"	s	"	"	"
6	"	b c	"	b	- - -	"	"	"	b c m	"
8	"	b	"	"	c	o s	- - -	o z q	b m	"
10	"	"	"	c	- - -	"	- - -	"	b q	"
12	o s	m q	"	"	- - -	"	s	b	"	"

Sept. 1, 7 A. M. The gale increasing, hove to 6 miles N. W. of Cape Alexander. 6 P. M. Made sail drifting to the southward of the Cape about 10 miles. Rounded Cape Alexander again at 11 P. M.; western shore distinctly visible.

Sept. 2, noon. Entered the pack 1 mile west of Littleton Island; continued beating through pack west of island; anchored on north shore of Hartstene Bay at 4 P. M. in 7 fathoms. Sept. 3, 4, 5. At anchor.

Sept. 6, 10 A. M. Towed the vessel toward Littleton Island; stopped by ice at north end of channel between McGary and Littleton Islands. Midnight, pulled out of the pack and made sail for Hartstene Bay.

Sept. 7. Came to anchor at 3½ A. M. between island and bluff west side of winter harbor.

Sept. 8. Commenced warping at 4 P. M.

Sept. 9, 8 A. M. Warping; at 5 P. M. moored the vessel in winter quarters, head to the east.

Sept. 11. Small pancake ice on the water 6 P. M.; strong ice blink in the west at 10 P. M.

Sept. 13. α Aurigæ very bright in N. W.; no other stars visible at 10; stars of second and third magnitude visible at 12.

Sept. 14, 18. Low mist bank near western horizon.

Sept. 19, 8 P. M. Pancake ice.

Sept. 20, 6 P. M. Fog bank near western horizon.

Sept. 21, 10 A. M. Pancake ice.

Sept. 22. Ice drifting in from outside; mist bank on west horizon.

Sept. 23, 5 A. M. Ice began moving, and at 6 had disappeared.

Sept. 24, 10 P. M. Clouds in N. W. illuminated by twilight.

Sept. 27, 8 A. M. Ice formed around the vessel nearly an inch thick.

Sept. 28, 10 A. M. Ice began drifting out of the harbor; 8 P. M. Fog bank near west horizon.

Sept. 29, 30. Mist on west horizon.

Record of the weather during October, 1860.

Hour	1st	2	3	4	5	6	7	8	9	10th
2	b	- - -	- - -	o	s	c	o s q	q	- - -	- - -
4	"	b	b	"	"	- - -	"	"	- - -	- - -
6	"	"	"	s	"	o s	"	"	- - -	- - -
8	"	b c	"	"	"	o	"	o q	o	b q
10	"	"	b c	"	"	"	"	"	"	b
Noon	"	"	o	"	o	"	"	"	o s	"
2	"	"	"	"	"	"	"	"	"	b c
4	"	"	"	"	"	"	"	o m q	"	"
6	"	"	o s	"	"	o s	"	"	b c	"
8	"	"	"	"	- - -	"	"	o q	"	"
10	b c q	"	- - -	"	- - -	"	"	"	b q	b
12	b	"	- - -	"	c	m q	"	"	- - -	- - -

Hour	11th	12	13	14	15	16	17	18	19	20th
2	- - -	- - -	- - -	- - -	- - -	b	- - -	b	b	b
4	- - -	- - -	- - -	- - -	- - -	"	- - -	"	"	"
6	- - -	- - -	- - -	- - -	- - -	"	- - -	"	"	"
8	- - -	o	o q	b c q	b	"	b c	b c	"	"
10	b c	o s	"	b c	"	"	- - -	"	"	"
Noon	"	"	"	b	"	"	- - -	b	"	"
2	"	"	"	"	"	"	- - -	"	"	"
4	b	"	b c	"	b c	"	- - -	"	"	"
6	"	"	"	"	"	"	b c	"	"	"
8	"	o	"	"	o	"	b	"	"	"
10	"	b c	- - -	"	"	"	"	"	"	"
12	"		- - -	"	b	"	"	- - -	"	"

Hour	21st	22	23	24	25	26	27	28	29	30	31st
2	b	o	b	b	b	b	- - -	b	o q	o	b
4	"	"	o	"	"	"	b	"	"	"	"
6	"	"	"	"	"	"	"	"	"	"	"
8	"	"	- - -	"	b c	b c	b c	"	"	"	s o
10	"	"	b c	b c	"	"	"	"	"	o s	o
Noon	"	"	"	"	"	"	"	b c	"	"	"
2	"	"	b	"	o	"	"	"	"	"	"
4	o	b c	"	"	o s	"	"	"	"	o	"
6	"	"	"	"	"	"	"	"	"	"	b
8	"	b	"	b	o	"	b	b	"	"	"
10	"	"	"	"	"	b	"	"	"	"	"
12	o s	"	"	"	b	- - -	"	"	"	"	"

October 2. At noon ice forming upon the surface of the water.
October 8, 4 P. M. Heavy mist bank on S. W. horizon.
October 12, noon to 6 P. M. Snow 6¼ inches deep.

Record of the weather during November, 1860.

Hour	1st	2	3	4	5	6	7	8	9	10th
2	*b*	*o*	*b*	*b*	- - -	*b*	*b*	*s*	*b*	*o s*
4	"	*b*	"	"	- - -	"	"	*o*	*o*	"
6	"	"	"	*o*	- - -	"	"	"	"	"
8	"	*b c*	*b c*	"	*b c*	"	*o*	*o s*	"	"
10	*b c*	"	"	"	"	"	"	*b c*	"	"
Noon	"	"	*o*	"	"	"	"	*o*	"	"
2	"	"	"	"	*b*	*b c*	"	"	"	"
4	"	*o*	"	"	"	"	"	"	"	"
6	"	"	"	"	"	*b*	"	"	*o s*	"
8	"	*b*	*b*	"	"	"	*o s*	"	"	"
10	"	"	"	"	"	"	"	"	"	"
12	"	"	"	*b*	"	*o*	- - -	*b*	"	"

Hour	11th	12	13	14	15	16	17	18	19	20th
2	*b*	*o*	*o*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
4	"	"	"	"	"	"	"	- - -	"	"
6	"	"	"	"	"	"	"	- - -	"	"
8	*o s*	"	*b c*	"	"	"	*o s*	*b*	"	"
10	"	"	"	*o*	"	"	"	"	"	"
Noon	"	"	"	*b c*	"	*b c*	"	"	"	"
2	"	"	"	*o*	"	"	*o*	"	"	"
4	"	"	"	"	*o*	"	"	"	"	*o*
6	"	"	"	*b*	"	*b*	"	"	"	"
8	*o*	"	"	"	*b c*	"	"	"	"	"
10	"	"	"	"	"	"	*b*	"	"	"
12	- - -	"	"	"	*b**	"	"	- - -	"	"

Hour	21st	22	23	24	25	26	27	28	29	30th
2	*o*	*b*	*b*	*o*	*s*	*b*	*s*	*o s*	*r s*	*s*
4	"	"	"	"	*o*	"	"	"	"	"
6	"	"	"	"	"	"	"	"	"	"
8	"	"	"	"	"	"	"	"	*b*	*o*
10	"	"	"	"	*s*	"	"	"	"	"
Noon	"	"	"	"	"	"	"	"	*b c*	"
2	"	"	"	*o s*	*o*	"	"	*o*	"	"
4	"	"	"	*s*	"	"	*o*	*r s*	"	*s*
6	"	"	"	"	"	*b c*	"	"	"	"
8	"	"	"	"	"	*o*	"	"	"	"
10	"	"	"	"	"	"	*s*	"	"	"
12	"	"	- - -	"	"	"	"	"	- - -	*o*

Record of the weather during December.

Hour	1st	2	3	4	5	6	7	8	9	10th
2	*b*	*o*	*b*	*b*	*o*	*o*	*b*	*b*	*b*	*b*
4	---	"	"	"	"	"	"	"	"	"
6	*o*	"	"	"	"	"	"	"	"	"
8	*b c*	"	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"	"	"
Noon	"	*b*	"	"	"	"	"	"	"	"
2	"	"	"	"	"	"	"	"	"	"
4	"	"	"	*o*	"	"	"	"	"	"
6	"	"	"	"	"	"	"	"	"	"
8	"	*o*	"	"	"	*b*	"	"	"	"
10	*o*	"	"	"	"	"	"	"	"	"
12	"	*c*	"	"	"	"	"	---	---	"

Hour	11th	12	13	14	15	16	17	18	19	20th
2	*b*	*o*	*b*	*b*	*b*	*b*	*b*	*s*	*o*	*s*
4	"	"	"	"	"	"	*o*	"	"	"
6	"	"	"	"	"	"	*o s*	"	"	*b*
8	*o*	*b*	"	"	"	"	"	"	"	*o*
10	"	"	"	"	"	"	"	"	"	"
Noon	"	"	"	"	"	"	"	"	*b c*	"
2	"	"	"	"	"	"	"	"	"	"
4	"	"	"	"	"	"	"	"	"	"
6	"	"	"	"	"	"	"	*b*	"	"
8	"	"	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"	"	"
12	"	"	"	"	"	"	---	"	*s*	*s*

Hour	21st	22	23	24	25	26	27	28	29	30	31st
2	---	*b*	*o*	*o*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
4	*b*	"	"	*b*	"	"	"	"	"	"	"
6	"	"	*s*	"	"	---	"	"	"	"	"
8	*o*	"	"	"	"	---	"	"	"	"	"
10	"	"	"	"	"	---	"	"	"	"	"
Noon	"	"	"	"	"	---	"	"	"	"	"
2	"	"	---	"	"	*b c*	"	"	"	"	"
4	"	"	---	"	---	"	---	"	"	"	"
6	"	"	---	"	---	"	---	"	"	"	"
8	*b*	"	---	"	---	"	---	"	"	"	"
10	"	*o*	*o*	"	---	---	---	"	"	"	"
12	"	"	*s*	"	*b*	*b*	*b*	"	"	"	"

Record of the weather during January, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2	*b*	*b*	*b*	*b*	*s*	*b*	*b*	*b*	*b*	*b*
4	"	"	"	"	*b*	"	"	*s*	"	"
6	"	"	"	"	"	"	"	"	"	"
8	"	"	"	"	"	"	"	"	"	"
10	"	*b c*	"	"	"	"	"	*b*	"	"
Noon	"	"	"	"	"	"	"	"	"	*b c*
2	"	*o*	"	"	"	"	"	*b m*	"	*b m*
4	"	"	"	"	"	"	"	*b*	"	*b c*
6	"	"	"	"	"	"	"	"	"	*o*
8	"	"	"	"	"	"	"	"	"	*o m*
10	"	"	"	"	"	"	"	"	"	*s*
12	"	*b*	"	*s*	"	"	"	"	"	*m s*

Hour	11th	12	13	14	15	16	17	18	19	20th
2	*s*	*b*	*b*	*s*	*b*	*b*	*b*	*b*	*b*	*b*
4	"	"	"	"	"	"	"	"	"	"
6	"	"	*z*	"	"	"	"	"	"	"
8	"	"	"	*m*	"	"	"	"	"	*z*
10	"	"	*z q*	*b*	"	"	"	"	"	"
Noon	"	"	"	"	"	"	"	"	*b c*	"
2	*o*	"	"	"	"	"	"	"	*z*	"
4	"	"	"	"	"	"	"	"	"	"
6	"	"	"	"	"	"	"	"	"	"
8	"	"	"	"	"	"	"	"	"	"
10	"	"	*s*	"	"	"	"	"	"	"
12	*b*	"	"	"	"	"	"	"	"	"

Hour	21st	22	23	24	25	26	27	28	29	30	31st
2	*b*	*b*	*b*	*b*	*b*	*b*	*m*	*m*	*o s*	*b*	*b*
4	"	"	"	"	"	"	"	"	"	"	"
6	"	"	"	"	"	"	"	"	"	"	"
8	"	"	"	*b m*	"	"	"	"	*o*	"	"
10	"	"	"	*b*	"	"	*s m*	"	*b c*	"	"
Noon	"	"	"	"	"	"	"	"	"	*b m*	"
2	"	"	"	"	"	"	"	*m*	"	"	"
4	"	"	"	"	"	*o*	*o*	*m*	*b*	*b*	"
6	"	"	"	"	"	"	"	*b*	"	"	*o*
8	"	"	"	"	"	"	*b*	"	"	"	*b*
10	"	"	"	"	"	"	"	"	"	"	"
12	"	"	"	"	"	"	"	"	"	"	"

January 5, 6. Aurora (see magnetic paper).
January 10, 8 P. M. Heavy mist hanging over the ice.
January 11. Heavy mist over the ice. Auroral display (see magnetic record).
January 25. At noon read without an artificial light.
January 28, 2 P. M. Heavy mist bank on S. W. horizon.
January 30, noon to 2 P. M. Heavy mist in S. W.

Record of the weather during February, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2	*b*	*s*	*b*	*b*	*b*	*b*	*b*	*b*	*s*	*b*
4	"	*b*	"	"	"	"	"	"	*b*	"
6	"	"	"	"	"	"	"	"	"	"
8	"	*s*	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"	"	"
Noon	"	"	"	"	"	"	"	"	*z*	"
2	"	*o*	*b c*	"	"	"	"	"	"	"
4	*o*	"	*m*	"	"	"	"	"	"	"
6	*s*	"	*b*	"	"	"	"	"	"	"
8	"	*b*	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"	"	*s*
12	"	"	"	"	"	"	"	*s*	"	"

Hour	11th	12	13	14	15	16	17	18	19	20th
2	*o*	*o s*	*b*	*z*	*b*	*b*	*b*	*b*	*b*	*b*
4	"	"	"	"	"	"	"	"	"	"
6	"	"	"	"	"	"	"	"	"	"
8	*s*	"	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"	"	"
Noon	"	"	"	"	"	"	- - -	"	"	"
2	"	"	"	"	"	"	*s*	"	"	"
4	"	"	"	"	"	"	"	"	"	"
6	"	*b*	*z*	"	"	"	"	"	"	"
8	*z*	"	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"	"	"
12	"	"	"	"	"	"	*b*	"	"	"

Hour	21st	22	23	24	25	26	27	28th
2	*b*	- - -	*b*	*z*	*b*	*b*	*b*	*b*
4	"	*b*	"	"	"	"	"	"
6	"	"	"	"	"	"	"	"
8	"	*s*	"	"	"	"	"	"
10	"	*o*	"	"	"	"	"	"
Noon	*b c*	"	"	"	"	"	"	"
2	"	"	"	"	"	"	"	"
4	*o*	"	"	"	"	"	"	"
6	"	"	"	"	"	"	"	"
8	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"
12	*b*	*s*	"	"	"	"	"	"

February 16, 9 P. M. An aurora visible.
February 18. Sun seen above the horizon.
February 19. Mock moon observed at 4 A. M.; one image on either side of the moon about 20° distant.
February 25, 2 P. M. Sun shining on deck.

Record of the weather during March, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2	*b*	*b*	*s*	*b*	*b*	*b*	*b*	*b*	*o*	*b*
4	"	"	*o*	"	"	"	"	"	*b*	"
6	"	"	*b*	"	"	"	"	"	---	"
8	"	*o*	*o*	"	"	"	"	*o*	*b c*	"
10	"	"	"	"	*b c*	"	"	"	"	*b c*
Noon	*b c*	"	"	"	"	"	"	"	*b*	*o*
2	*c*	*o s*	"	"	"	"	"	"	"	*s*
4	"	"	"	"	"	"	"	"	"	"
6	"	"	"	"	"	"	"	*b*	"	*b c*
8	*c s*	"	"	"	"	"	"	"	"	*s*
10	"	"	"	"	*b*	"	"	"	"	"
12	*b*	"	"	"	"	"	"	"	"	"

Hour	11th	12	13	14	15	16	17	18	19	20th
2	*s*	*s*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
4	"	"	"	"	"	"	"	"	"	"
6	"	"	"	"	"	"	"	"	"	"
8	*c*	*b*	"	"	"	"	"	"	"	"
10	"	"	"	"	*b c*	"	"	"	"	"
Noon	*b*	"	"	*z*	"	"	"	"	"	"
2	"	"	"	"	*b*	"	"	"	"	"
4	*s c*	"	"	"	"	"	"	"	"	"
6	*s*	*z*	"	"	"	"	"	"	"	"
8	"	"	"	"	"	"	"	"	"	"
10	"	---	"	"	"	"	"	"	"	"
12	"	*b*	"	*b*	"	"	"	"	"	"

Hour	21st	22	23	24	25	26	27	28	29	30	31st
2	*b*	*b*	*b*	*b*	*o*	*b*	*b*	*s*	---	*b*	*b*
4	"	"	"	"	*s*	"	"	"	*c*	"	"
6	"	"	"	"	"	"	"	"	*b*	"	"
8	"	*b c*	"	"	"	"	*o*	*z*	"	*c z*	*b c*
10	"	"	"	"	"	"	"	"	"	"	*c*
Noon	"	"	"	"	"	"	"	"	"	*b z*	"
2	"	"	"	"	"	"	"	"	*z*	*c*	"
4	"	"	*b c*	"	"	"	"	*o*	*z b*	*o*	*o*
6	"	"	*b*	"	"	"	"	"	"	"	"
8	"	"	"	"	"	"	"	"	*z c*	"	"
10	"	"	"	"	"	"	"	"	"	*c*	"
12	"	"	"	*o*	"	"	*s*	*b*	---	*b*	*b*

March 31. Read at midnight without artificial light.

Record of the weather during April, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2	*b*	*b*	*b*	*b*	*z q*	*c*	*b c*	*b*	*o*	*b*
4	"	"	"	"	"	*s o*	- - -	"	"	"
6	"	- - -	"	"	"	"	- - -	"	"	"
8	"	*o*	"	"	*b q*	"	*z*	"	*c*	*o*
10	"	"	"	"	*c q*	*o*	"	"	"	"
Noon	*c*	"	"	"	"	"	"	*c*	"	*b*
2	"	"	"	"	"	"	"	"	"	*c*
4	*o*	"	"	"	"	"	*b*	"	"	"
6	"	"	"	"	"	"	"	*o*	"	"
8	*c*	"	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"	"	"
12	*b*	*s*	"	*c*	"	"	"	"	"	*o*

Hour	11th	12	13	14	15	16	17	18	19	20th
2	*o*	*b*	*b*	*z*	*b*	*b*	*b*	*o*	*b*	*b*
4	"	"	*c*	"	"	"	"	*b*	"	"
6	"	"	"	"	"	"	"	"	"	"
8	*z*	*o*	*m*	"	"	"	*b c*	"	*m*	*c*
10	"	*s*	"	"	"	"	- - -	"	"	"
Noon	"	"	"	*b*	"	"	*o*	"	"	"
2	"	"	"	"	"	"	"	"	"	"
4	"	*b c*	*o*	"	"	"	"	"	"	"
6	"	*o*	*z*	"	"	"	"	"	"	"
8	"	"	"	"	"	"	*s*	"	"	"
10	"	*b*	"	"	"	"	*o*	"	"	"
12	"	"	"	"	"	"	"	"	"	*o*

Hour	21st	22	23	24	25	26	27	28	29	30th
2	*o s q*	*z*	*b*	*s*	*s*	*b*	*b*	*b*	*b*	*b*
4	"	*o*	"	"	"	"	"	"	*c*	"
6	"	"	"	"	"	"	"	"	"	"
8	"	"	"	"	*b*	"	"	"	*z*	"
10	"	*c*	"	"	*z*	"	"	"	"	"
Noon	"	*b*	"	"	"	"	"	"	"	"
2	"	"	"	"	"	"	"	"	*c*	"
4	"	"	*o*	"	"	"	"	*c*	"	"
6	"	"	*s*	"	*c*	*c*	"	"	"	"
8	"	*c*	"	"	"	"	"	"	"	"
10	"	"	*o*	"	"	*o*	"	"	"	"
12	"	*b*	*s*	"	*b*	"	"	"	"	"

April 18. At noon snow melting on side of ship.

Record of the weather during May, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2	*b*	*b*	*b*	*b*	*o*	*b*	*b*	*o*	*s*	*b*
4	"	"	*o*	*s*	"	"	"	"	"	"
6	"	"	"	"	"	"	"	*s*	*o*	"
8	"	"	"	"	*b*	"	"	"	"	"
10	"	"	*b*	"	"	"	"	"	*b*	"
Noon	"	*c*	"	"	"	"	"	"	"	"
2	"	"	"	"	"	"	"	"	"	"
4	"	"	"	"	"	*c*	"	"	"	"
6	"	*b*	"	"	"	*b*	"	"	"	"
8	"	"	"	*o*	"	"	*o*	"	"	"
10	"	"	"	"	"	"	"	"	"	"
12	"	*c*	"	"	"	"	"	"	"	"

Hour	11th	12	13	14	15	16	17	18	19	20th
2	*b*	*b*	*b*	*b*	*b*	*b*	*o*	*b*	*o*	*b*
4	"	"	"	"	"	*o*	"	"	"	"
6	"	"	"	"	"	"	*s*	"	*s*	"
8	"	"	"	"	"	"	*s m*	*o s*	"	"
10	"	"	"	"	"	"	"	"	*b*	"
Noon	"	"	"	"	"	"	"	"	"	"
2	"	"	"	"	*o*	"	"	"	- - -	"
4	"	"	"	"	*b*	*m*	*c*	*o s m*	*c*	"
6	"	"	*c*	"	"	"	"	"	*b*	"
8	"	"	"	"	*c*	*m s*	"	"	"	"
10	"	"	"	"	*o*	- - -	"	"	"	*c*
12	"	"	*b*	"	*b*	*o*	*o*	"	"	"

Hour	21st	22	23	24	25	26	27	28	29	30	31st
2	*b*	*o*	*b*	*b*	*b*	*b*	*o*	- - -	*b*	*b*	*b q*
4	"	"	"	"	"	"	"	- - -	"	"	*s q*
6	*o*	*b*	"	"	"	"	"	- - -	"	"	*b q*
8	"	*c*	"	"	"	"	"	*c*	"	"	"
10	"	*b*	"	"	"	"	"	"	"	"	"
Noon	*s*	"	"	"	"	"	*c*	*s*	"	"	"
2	*o*	"	"	"	"	"	"	*o*	"	"	"
4	"	"	"	"	"	"	"	*c*	"	*c s*	"
6	"	"	"	"	"	"	"	"	"	*c s q*	"
8	"	"	"	"	"	"	*b*	"	"	"	"
10	"	*c*	"	"	"	*c*	"	*b*	"	*o s q*	*c s q*
12	"	"	"	"	"	"	"	"	"	- - -	*q*

May 12. Water running down the hills.
May 16, 4 and 6 P. M. Thick mist over the hills and over the ice.
May 17, 8 A. M. to 2 P. M., and 18, 4 P. M. to midnight. Mist bank in S. W

Record of the weather during June, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2	*b*	*b*	*o*	*s*	*o*	*b*	*o*	*b*	*b*	*b*
4	"	"	"	"	*s*	"	"	"	"	"
6	"	"	"	- - -	*m*	"	*b*	"	"	"
8	"	*c*	"	- - -	"	- - -	"	"	"	"
10	*c*	"	"	*o*	"	*c*	"	"	*c*	"
Noon	"	"	"	"	*o*	"	"	"	"	"
2	"	*o*	"	"	*c*	"	"	"	"	"
4	"	"	"	"	*b c*	"	"	"	"	*c*
6	"	"	"	"	*b*	"	"	"	"	"
8	*s*	"	"	"	"	"	"	"	"	"
10	"	"	"	"	"	*b*	"	*c*	"	"
12	*b*	"	*o s*	*b*	"	"	"	"	"	*o*

Hour	11th	12	13	14	15	16	17	18	19	20th
2	*o*	*o*	*b*	*b*	*b*	- - -	*s q*	*s q*	*o*	*o*
4	"	"	"	"	"	- - -	"	"	"	"
6	"	"	"	"	"	- - -	"	"	"	*b*
8	*s*	"	"	"	"	*s q*	- - -	"	*s*	*b c*
10	*o*	"	"	*c*	"	"	*c q*	"	"	"
Noon	"	"	*c*	"	"	"	"	"	"	*b*
2	"	*s*	"	"	"	"	"	"	*o*	"
4	"	*c s*	*c s*	"	"	"	"	"	"	"
6	"	"	"	"	"	"	"	"	"	"
8	"	*c q*	*b*	*b*	"	"	"	"	"	"
10	"	- - -	"	"	"	"	*s q*	"	"	"
12	"	*s*	"	"	"	*q o*	"	"	*q*	*c*

Hour	21st	22	23	24	25	26	27	28	29	30th
2	*b*	*b*	*o*	*b*	*o*	*r*	*r*	*s*	*b*	*s*
4	"	"	"	"	"	"	"	"	"	"
6	"	"	"	*c*	"	"	"	"	*c*	"
8	"	*c*	"	- - -	"	"	"	"	"	"
10	"	"	"	*o*	*r*	"	"	"	*o m*	*r*
Noon	"	"	"	"	"	"	"	"	*r*	- - -
2	"	*o*	"	"	"	"	"	*o*	"	*o m*
4	"	*c*	"	"	"	"	*o*	*r*	*s*	"
6	"	- - -	"	"	"	"	*r*	*o*	"	*f*
8	"	*b*	*c*	"	"	*o*	*s*	"	"	"
10	*c*	*c*	"	"	"	- - -	"	"	"	*r*
12	- - -	"	*o*	"	*r q*	*r q*	"	*b*	"	*o*

June 28. Amount of rain and snow in 48 hours was found to be 0.44 of an inch.
June 30. Amount of rain and snow fallen in 22 hours was found to be 0.25 of an inch.

Record of the weather during July, 1861.

Hour	1st	2	3	4	5	6	7	8	9	10th
2	*m*	*o s*	- - -	*b*	*s*	*b*	*b*	*b*	*c*	*b*
4	*r*	"	*o*	"	"	"	"	"	"	"
6	- - -	"	"	*c*	*b*	"	"	"	"	"
8	*o*	"	"	"	"	*c*	"	*c*	*b*	*o q*
10	"	"	"	"	*c*	"	"	- - -	"	*c q*
Noon	"	"	*b*	"	"	*b*	*f*	- - -	"	"
2	"	"	"	"	"	"	*b*	*o*	"	"
4	"	"	"	*s*	*o*	"	"	*r*	"	*o*
6	"	"	"	"	"	"	"	*o*	"	"
8	"	"	"	"	"	"	"	"	"	"
10	*c*	"	*c*	"	*c*	"	"	"	"	"
12	"	"	- - -	"	*b*	"	"	*c*	"	*b*

Hour	11th	12	13	14	15	16	17	18	19	20th
2	*b*	*b*	*s*	*b*	*c*	*c*	*c*	*r*	*c*	*c*
4	"	"	"	"	*b*	"	"	"	*r*	*b c*
6	*o*	"	"	"	"	"	"	*c*	"	"
8	"	"	"	"	"	"	"	"	"	"
10	"	"	- - -	"	"	"	"	"	"	"
Noon	"	"	*o*	"	"	"	"	"	*c*	*c*
2	*c*	"	*c*	"	"	*s*	"	"	*r*	"
4	"	"	"	"	"	"	"	"	*c*	*r*
6	"	"	"	"	"	"	"	"	"	"
8	"	"	"	"	"	*c*	"	"	"	*f*
10	"	"	"	*c*	*c*	*r*	"	"	"	*c*
12	*b*	"	"	"	"	*c*	"	"	"	"

Hour	21st	22	23	24	25	26	27	28	29	30	31st
2	*r*	*f*	*s*	*c*	*s*	*c*	*b*	*b*	*b*	*b*	*f*
4	*c*	"	"	"	"	"	*f*	"	"	"	"
6	*r*	*b*	"	"	"	*r*	"	"	"	"	"
8	*s*	"	*o*	"	"	"	*b*	"	"	"	*c*
10	"	"	"	"	"	*c*	"	"	"	"	"
Noon	"	*c*	*s*	"	"	"	"	"	"	"	"
2	*o*	*s*	- - -	"	"	"	"	"	"	*c*	*f*
4	"	"	*c*	"	*r*	"	"	"	"	"	"
6	*r*	"	"	*s*	*c*	"	"	"	"	"	*o*
8	"	*c*	"	*o*	"	*b*	"	"	"	*f*	"
10	*o*	"	"	"	"	"	"	*c*	"	"	*f*
12	"	*s*	"	*s*	"	"	"	*b*	"	"	"
Temp. of water.							32°.4	35°.1	33°.8	35°.1	35°.7

July 14, 10 A. M. Unmoored ship and pulled out of Port Foulke. 7 P. M. Made fast to an iceberg one mile south of Port Foulke.

July 15. Got under way at 1h 30m P. M.; made the open water at 2h 25m; stood towards Cape Isabella; a thick fog coming on, moored in 3 fathoms water in channel between McGary and Littleton Islands.

July 27, 10½ A. M. Got under way and stood towards the west coast; observed latitude 78° 22′ N. among the floe ice off Cape Isabella. At 5½ P. M. (Green. time), in a line with Capes Ingersoll and Inglefield.

July 28, 3 A. M. Made fast to an iceberg. 6 A. M. Heading for first point south of Cape Isabella. 10 A. M. Let go anchor, half a mile from shore, in a large bay ten miles south of Cape Isabella, in 9 fathoms water. New ice on surface of water.

July 29, 1 P. M. Up anchor and pulled through ice to the southward. At 3½ becalmed; fastened to an iceberg off Gale Point. 8 P. M. Cast off and commenced warping from floe to floe. 10 P. M. Many narwhals and seals in the vicinity of the schooner. At midnight opposite Paget Point met heavy pack ice; kept along the margin of it.

July 30, 6 A. M. Mattie Island bears W. by S.; Cape Faraday N. W. by W.; Gale Point N. by E. 7 P. M. Shut in with a thick fog; tacked ship, head to S. W. 11 P. M. Fell in with the pack stretching E. and W.; wore ship to S. E.

July 31. Wore ship to N. at 10 A. M., Northumberland Island bears S. E.

	August 1, 1861.					August 2.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea- ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea- ther.	
2	E. S. E.	29in.90	46°	32°	*f*	calm	29in.92	47°	39°	*b*	Aug. 1, 4 A. M. Cape Sabine N. ¾ E., Cape Isabella N ½ W. 6 A. M. Mittie Island N. W. by W., Cape Faraday N. W. ½ N., Cape Isabella N. by E., Coburg Island W. S. W., high land on east coast N. E. by E.
4	"	.80	45	33	*b*	E. N. E. 1	.92	49	45.5	"	Aug. 2, 8½ A. M. Commander went ashore; returned at 11 A. M. At 2 P.M. south part of Hakluyt Island bears S. (mag. ?). 4 P. M., south point of Northumberland Island S. by W. (mag.).
6	E. S. E. 2	.85	46.5	34.5	*c*	W. 1	.85	51	42	"	
8	E. S. E. 2	.90	38	34	*b*	"	.90	53	46	"	
10	E. S. E. 1	.90	48	36	"	"	.94	51	43	"	
Noon	S. 1	.85	49	36	"	"	.85	- -	38	"	
2	N. N. E. 1	30.00	50	35	"	W.S.W. 2	.96	46	37	*f*	
4	E. by N. 1	29.90	- -	36	"	W.S.W. 1	.98	45	37	"	
6	calm	.95	51	44	"	"	30.00	53	37	"	
8	"	.95	51	45	"	N. N. E. 1	29.87	49	34	"	
10	W.	.97	49	40	"	E. N. E. 2	.90	49	33	"	
12	calm	.85	45	37.5	"	S. E. 1	.90	52	32	"	
	Temp. water, 35°.6.					T. W. 36°.2.					

	August 3.[1]					August 4.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea- ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea- ther.	
2	N. N. E. 3	29.95	52	32	*h*	N. E.	29.90	51.5	38.5	*b*	
4	"	.85	50	32.5	*f*	"	.90	49	37	"	
6	- - -	.80	53	37	"	"	.91	47.5	41.5	"	Aug. 4. At anchor.
8	calm	.87	55	38	*b*	calm	.84	51	50.5	"	
10	"	.87	56	40.5	"	- - -	.94	52	47	"	
Noon	"	.90	56	39	"	- - -	.90	55	48	"	
2	S. 1	.82	58	37.5	"	calm	.97	60	45	"	
4	- - -	- -	- -	- -	"	"	30.03	61	44	"	
6	S. S. E. 1	.88	55	41	"	"	.00	56	51	"	
8	N. E. 1	.85	53	41	"	"	29.96	52	46.5	*c*	
10	"	.87	55	43	"	"	.98	51	47	*b*	
12	calm	.92	53	40.5	"	"	30.00	51	40	"	
	T. W. 36°.2.					T. W. 38°.9.					

	August 5.					August 6.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea- ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea- ther.	
2	N. W. 2	29.98	50	38	*b*	calm	29.90	55	41	*b*	
4	N. W. 1	.90	50	37	"	N.	.85	48	35	"	
6	"	30.00	51	45	"	"	.90	53	37	"	
8	"	29.96	52	47	"	"	.90	- -	38	"	
10	"	30.00	50	45	"	"	.90	50	38.5	"	
Noon	"	29.96	48	41	"	"	.97	49	47	"	
2	N. E. 2	.94	48	42.5	"	calm	.97	49	48	"	
4	N. E. 1	.95	49	48	"	"	.98	50	47	"	
6	N. E. 3	.96	50	46	"	"	.98	50.5	49	"	
8	N. E. 1	.95	50	46	"	"	.87	56	48	"	
10	"	.90	53	43	"	N. E. 1	.92	56	41.8	*c*	
12	"	.88	52	39	"	"	.90	57	41	*b*	
	T. W. 38°.0.					T. W. 37°.2.					

[1] Remarks noted at end of month's record.

	August 7.					August 8.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	- - -	- -	- -	- -	b	N. E. 1	$29^{in}.91$	56°	39	c	Aug. 8. Got under way at 10 A. M. At noon south point of Northumberland Island bears S. E. by E. ½ E., and south point of Netlik bears S. ½ W. At 2½ P.M. Cape Parry bears due E. (true) distance 1 mile; at 4½ Fitz-clarence rock bears E. (three miles). 4½ P. M. Commander went ashore.
4	- - -	- -	- -	- -	- -	"	.97	56	39.5	b	
6	- - -	- -	- -	- -	- -	calm	.98	58	42	"	
8	calm	$29^{in}.92$	54°	47°.5	b	N. 1	.97	58	42.5	"	
10	- - -	- -	- -	- -	- -	"	30.00	55	43	"	
Noon	calm	95	54	41.5	b	"	29.98	54	43	"	
2	"	.93	53	47	"	W. 2	30.05	54	41	"	
4	N. E. 1	.95	53	42	"	W. 1	29.98	58	42	"	
6	"	.93	54	45	"	N.N.W. 1	30.02	57	46	"	
8	calm	.91	56	42	"	"	.00	- -	46	"	
10	"	.98	52	43	"	N. E.	.01	56	42	"	
12	"	.93	58	41	c	"	.00	55	38	"	
	T. W. 37°.9.					T. W. 37°.9.					

	August 9.					August 10.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	calm	29.90	55	39	c	E. S. E. 1	29.80	51	38	b	Aug. 9, 4 A. M. Strong current setting to westward. 8 P. M. Cape Parry bears N. by W., and southern part of Saunders Island S. E. ½ S. Aug. 10. At 0^h Cape Parry N. ¼ E. south point of Wolstenholm S. E. ½ S. Fitz-clarence Rock N. N. E. ¾ E.
4	"	.90	54	39.5	"	"	.75	50	40	"	
6	"	.85	53	41	b	S. E.	80	51	45	"	
8	"	.90	54	48	"	"	.82	59	44.5	"	
10	"	.90	53	49	"	N. W. 3	.90	54	42.5	"	
Noon	"	.87	53	48	"	N. W. 4	.92	54	40	"	
2	"	.90	53	45	c	E. 6	.80	54	44	b c	
4	"	.95	55	47	b	"	.80	50	38	c	
6	"	.80	- -	46	"	"	.85	51	37.5	"	
8	S. 1	.87	54	42.5	"	"	.90	53	40.5	b	
10	W.S.W. 2	.97	55	42	c	"	.75	52	39	"	
12	"	.92	52	40.8	"	"	.80	51	38	"	
	T. W. 39°.0.					At noon obser'd lat. 76° 12′ Long. by chr. 70 53 Var'n, 106° W. T. W. 38°.4					

	August 11.					August 12.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	E. 6	29.82	50	39.5	b	N.N.E. 3	29.77	53	33	b	Aug. 11. At midnight horizon free of ice from N. E. to S. W. At 9½ A. M. made the pack, ran along the margin to the south; entered the ice at 10½. Aug. 12, 4 A. M. Fell in with the whaling bark "Polar Star," of Peterhead Eng.
4	"	.80	48	40	"	"	.80	52	36.5	"	
6	"	.90	47	40	"	"	.70	48	35	"	
8	"	.90	50	39	"	"	.75	49	34	f	
10	"	.80	50	35	"	"	.75	50	36	"	
Noon	"	.70	52	36	"	N.N.E. 1	.70	50.5	36	"	
2	N. E. 5	.82	55	37.5	"	- - -	.80	53.5	35	"	
4	"	.80	53	40	"	N. W. 1	.82	50.5	34.5	"	
6	"	.75	58	38	"	calm	.75	50	33	"	
8	N.N.E. 4	.74	60	36	"	"	.73	55	31	"	
10	"	.75	58	35	"	"	.90	50.5	31.5	"	
12	"	.75	54	32.5	"	N. by W. 1	.90	49.5	31	"	
	Obs'd lat. 74° 19′ long. 66 00 at noon T. W. 35°.0.					At noon lat. by D. R. 74° 02′ long. 60 16 W. var. 7½ pts. T. W. 34°.9.					

	August 13.					August 14.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	W.S.W.1	$29^{in}.80$	48°	33°	*f*	W. 1	$29^{in}.68$	57°	37°	*o*
4	variable	.75	48	33	"	N. E. 1	.65	56	37	"
6	W.S.W. 1	.70	48	34	"	calm	.80	55	41.5	"
8	"	.78	50	36	*s*	"	.80	57	47	"
10	"	.70	53	38	*o*	"	.75	52	47	"
Noon	"	.81	77	40	*c*	"	.85	54	45.5	"
2	E. N. E. 1	.80	64	40.5	*o*	"	.75	56	46	*b*
4	"	.88	68	39	"	"	.70	50.5	41	"
6	E.	.78	65	39	"	N. E. 2	.70	52.5	45	"
8	"	.77	62	39	*s*	"	.75	50	40.5	"
10	variable	.75	66	37	"	"	.75	51	38	"
12	"	.85	62	36.5	"	"	.80	50	36	"

Lat. by obs'n, 73° 40′
Long. by chr. 58 46
W. var. 80°. T. W. 39°.4.

T. W. 40°.0.

Aug. 13. At 7½ A. M. made the land bearing N. E. by E. (true); at 9½ A. M. a small island in sight bears N. E. by N. ½ N. (true). 2 P. M. Land in sight to the eastward.

Aug. 14, 11 P. M. Came to anchor in Upernavik Harbor.

	Aug. 15.					Aug. 16.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	calm	29.85	52	35	*b*	N. W. 1	30.05	60	35	*m*
4	"	.80	52	35.5	"	"	29.95	58	36	*b*
6	"	.75	50	33	"	"	30.00	49	36	"
8	"	.70	50	42	"	"	29.99	55	39	"
10	"	.80	50	48	"	"	.97	57	47	"
Noon	"	- -	- -	52	"	"	.98	58	- -	"
2	N. E. 1	.90	52	52	"	calm	.90	56	51	"
4	"	.95	50.5	50.5	"	E. N. E. 1	.50	54	50	"
6	- - -	.90	51	41	"	"	.80	51	50	"
8	- - -	30.10	60	38.5	"	"	.90	56	41.8	"
10	- - -	.05	60	- -	"	"	.92	54	38.5	"
12	N. W. 2	.10	60	38.5	*f*	"	.95	52	36	"

T. W. 39°.8.

T. W. 41°.3.

	August 17.					August 18.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	E.N. E. 1	29.94	53	36.5	*c*	- - -	- -	- -	- -	- -
4	"	.95	53	36	"	E.N.E. 1	29.90	52.5	37	*b*
6	"	.92	53	45	"	- - -	- -	- -	- -	"
8	"	.92	53	45	*b*	- - -	- -	- -	39	"
10	calm	.92	54	55	"	- - -	- -	- -	- -	"
Noon	E. N. E. 1	.90	51.5	- -	"	- - -	- -	- -	43	"
2	"	.93	55	51	"	- - -	- -	- -	- -	- -
4	- - -	- -		- -	"	N. W. 1	29.95	51	39.5	- -
6	E. N. E. 1	.82	51.5	48	"	- - -	- -	- -	- -	- -
8	"	.85	51	42	"	N. W. 1	.87	52	38	- -
10	- - -	- -	- -	- -	"	- - -	- -	- -	- -	- -
12	- - -	- -	- -	32	"	N. W.	.80	53	36	- -

T. W. 40°.1.

T. W. 36°.8.

	August 19.					August 20.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	N. W.	- -	- -	36°	- -	calm	- -	- -	36°	*r*
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	N. W.	$29^{in}.86$	50°	36	- -	calm	$29^{in}.78$	52°	36	*r*
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
Noon	N. W.	.77	49	39.2	- -	calm	.76	49	38	*r*
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	calm	.82	48	44	- -	- - -	.75	50	36	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	calm	.81	52.5	41	- -	- - -	- -	- -	35	- -
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
12	calm	- -	- -	39	- -	- - -	- -	- -	35	- -
	T. W. 38°.8.					T. W. 37°.5.				

	August 21.					August 22.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	- - -	- -	- -	35	- -	- - -	- -	- -	37	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	- - -	29.78	55	37.5	- -	N. E. 1	29.72	52	37	- -
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
Noon	N. W. 1	.72	56	40	- -	N. E. 1	.68	49	41	- -
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	- - -	.69	52	40	- -	N. 1	.68	47	45	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	- - -	.70	52	39	- -	N. 1	- -	- -	35	- -
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
12	N. W. 1	.67	54	36.5	- -	N. 1	.65	40	35	- -
	T. W. 38°.9.					T. W. 38°.3.				

	August 23.					August 24.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	N. 1	- -	- -	33	- -	N. 2	29 78	40	30	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	N. 1	29.70	50	41	- -	N.	.80	41	32	- -
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
Noon	- - -	- -	- -	- -	- -	- - -	- -	- -	51	- -
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	N. 2	.75	44	43.5	- -	S. W. 1	.75	45	47	*o*
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	N. 2	.73	43	37	- -	S. W.	.80	51.5	37	*h*
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
12	N. 2	- -	- -	35	- -	S. W.	- -	- -	32	- -
	T. W. 37°.7.					T. W. 35°.8				

	August 25.					August 26.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	- - -	- -	- -	- -	- -	E.N.E. 3	$29^{in}.97$	53°	35°	b	Aug. 25. At noon left Upernavik.
4	- - -	- -	- -	35°	- -	E.N.E. 2	.95	52.5	35	"	
6	- - -	- -	- -	- -	- -	E.N.E. 1	30.10	51	37	"	
8	calm	$29^{in}.87$	52°	39	c	calm	.20	50	40	"	
10	- - -	- -	- -	- -	- -	E.N.E. 2	.12	54	37	"	
Noon	N. E. 2	.87	56	46.5	b	"	.10	53	36	"	
2	N. 2	.90	51	40	"	E.N.E. 1	.10	54.5	40	c	
4	E. by N. 4	.95	51	39	"	E.N.E. 2	29.97	54	41	b	
6	"	30.05	52	38	"	E.N.E. 3	30.00	52	38	"	
8	E.N.E. 3	29.90	50	35	"	"	.20	52	37	"	
10	"	30.00	51.5	34.5	"	E.N.E 4	.10	51	37	"	
12	"	29.98	51	34.5	"	"	.05	47	36	c	
	T. W. 38°.6.					Lat. 71° 26′; long. 56° 0′ at noon. T. W. 38°.1.					

	August 27.					August 28.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	E.N.E. 4	30.10	48	36	b	calm	30.02	55	36	b	Aug. 27. At noon off Mellen Fiord.
4	"	.00	54	36	"	var.	.05	55	38	"	
6	E.N.E. 2	.02	53	37.5	"	"	.02	54.5	41	"	
8	E.N.E. 1	.10	54	43	"	S. S. W. 1	.05	54	45	"	
10	"	.05	54	41	"	"	.00	53	45	"	
Noon	var.	.05	52	39	"	"	.00	51	46	"	
2	"	29.50	54	44	"	"	29.95	51	42	"	
4	"	.60	53	43	"	"	.95	52	50	f	
6	N. E. 1	.95	51	41	"	"	30.05	52	43	"	
8	N. E. 3	.70	52.5	39	"	"	.02	52	37	"	
10	calm	30.10	58	38	"	"	29.97	50.5	36.5	"	
12	"	29.80	60	37	"	"	.90	48	38	"	
	Lat. 69° 47′; long. 55° 11′ T. W. 39°.7.					At noon lat. 69° 35′; long. 54° 43′ T. W. 42° 0.					

	August 29.					August 30.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	S. W. 1	29.95	46	37	f	S. E.	29.90	58	45	b	Aug. 29, 4 A. M. Strong current setting in to the northward. 2 P. M., do.
4	"	.92	46	38	"	"	.50	56	39	"	
6	"	30.00	46	37	b	S. by W.	.75	53	41	"	
8	calm	.10	50	40	"	S. S. W. 2	.85	51	42.5	"	
10	"	29.95	52	47	"	"	.90	54	47	"	
Noon	"	.95	57	44	"	S. S. E. 5	.85	50	45.5	"	
2	S.	.90	55	50	"	"	30.00	50	42	c	
4	"	.85	57	54	"	"	29.90	51	45	"	
6	calm	.90	56	50	"	S. S. E. 4	.87	49	43	"	
8	"	.87	60	42	"	S. S. E. 2	.90	54	43	"	
10	W. 1	.90	64	40	"	"	.95	53	43	"	
12	S. E.	.95	60	40	"	"	30.10	51	43	"	
	T. W. 41°.2.					T. W. 40°.7.					

August 31.							
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.		
2	calm	29in.95	53°	43°	c		Aug. 31. At 9 A.M. came to anchor in Godhavn.
4	"	30.10	55	44	"		
6	"	.00	53	41	"		
8	- - -	- -	- -	- -	"		
10	- - -	- -	- -	- -	"		
Noon	W. 1	.10	53.5	41	"		
2	- - -	- -	- -	- -	- -		
4	- - -	.00	50	43	- -		
6	- - -	- -	- -	- -	- -		
8	- - -	.20	50	38	- -		
10	- - -	- -	- -	- -	- -		
12	- - -	- -	- -	40	- -		
T. W. 39°.9.							

August 3, 0h A. M. Made fast to an iceberg; Hakluyt bears N. W. ½ N. (true). 2 A. M. South part of Herbert Island bears E. N. E. (true); distance ¼ mile; no bottom with 69 fathoms. 9 A. M. Cast off from berg and stood for Netlik. During the night experienced a very strong current setting from S. W. (true). 10½ P. M. Came to Netlik Harbor in 6 fathoms water. A rock in mid channel, dry at ¾ ebb, bears about S. W. from N. E. point of harbor.

Hour	September 1, 1861. Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea. ther.	September 2. Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -	Sept. 1. At anchor.
4	- - -	- -	- -	40°	- -	- - -	- -	- -	32°	- -	
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -	
8	- - -	30in.10	52°	38.5	r	N. E. 2	29in.90	55°.5	33	c s	
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -	
Noon	- - -	.10	50.5	39	r	- - -	- -	- -	- -	- -	
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -	
4	- - -	.15	- -	39	r	- - -	- -	- -	- -	- -	
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -	
8	- - -	.10	50	39	- -	- - -	- -	- -	- -	- -	
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -	
12	- - -	- -	- -	38	- -	S. W.	- -	- -	- -	- -	
	T. W. 39°.7.					T. W. 37°.7					

Hour	September 3. Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	September 4. Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -	
4	S. W.	- -	- -	34	- -	S. W.	- -	- -	34	s	
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -	
8	S. W. 1	30.00	54	37	o	S. E. 1	29.90	49	- -	- -	
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -	
Noon	S. W. 1	29.87	55	41	o	- - -	- -	- -	- -	- -	
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -	
4	S. W.	- -	- -	39.5	- -	S. E.	- -	- -	- -	- -	
6	- - -	- -	- -	- -	- -	"	- -	- -	- -	- -	
8	S. W.	.95	50	35	- -	S. E.	- -	- -	- -	- -	
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -	
12	S. W.	- -	- -	34.5	- -	S. E.	- -	- -	- -	- -	
	T. W. 39°.3.					T. W. 38°.5.					

	September 5.					September 6.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	S. E.	- -	- -	33°	- -	S.	- -	- -	27°	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	S. E.	30in.14	48°	37.5	- -	- - -	- -	- -	- -	- -
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
Noon	S. 3	.22	49	39	- -	S. W. 1	29in.95	50°.5	33	*b*
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	- - -	- -	- -	- -	- -	N. 1	.81	47.5	34.5	*c*
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	- - -	- -	- -	- -	- -	- - -	.79	47.5	31	- -
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
12	S.	.11	38	37	- -	- - -	- -	- -	28	- -
	T. W. 37°.7.					T. W. 38°.0.				

	September 7.					September 8.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	- - -	- -	- -	27	- -	- - -	- -	- -	32	- -
6	- - -	29.80	51	32	- -	- - -	- -	- -	- -	- -
8	- - -	- -	- -	- -	- -	S. E. 4	29.72	50.5	37	*b*
10	- - -	.86	58	34	- -	- - -	- -	- -	- -	- -
Noon	- - -	- -	- -	- -	- -	S. E. 4	.65	50.5	39	*b*
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	W. 1	.91	55	34.5	- -	S. E. 4	.56	52	41	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	S. E. 2	- -	- -	34	*c*	S. E.	- -	- -	39	- -
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
12	- - -	- -	- -	31	- -	calm	- -	- -	38	- -
	T. W. 37°.0.					T. W. 37°.3.				

	September 9.					September 10.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	- - -	- -	- -	37	- -	- - -	- -	- -	41	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	S. E. 3	29.52	52.5	41	*c*	S. W. 3	29.65	50	45	*b*
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
Noon	S. E. 4	.52	55	43	*o q*	- - -	.63	58	43.5	- -
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	S. E. 1	.52	59.5	47	- -	- - -	- -	- -	- -	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	S. E.	- -	- -	42	- -	S. E. 1	.77	59.5	- -	- -
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
12	S. E.	- -	- -	43	- -	- - -	- -	- -	- -	- -
	T. W. 39°.4.					T. W. 39°.4.				

	September 11.					September 12.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	- - -	- -	- -	38°	- -	- - -	- -	- -	39°	c
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	- - -	- -	- -	- -	- -	calm	29in.65	59°	37	r
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
Noon	N. 1	29in.85	50°	40	r	calm	.75	59	36	o
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	N. W. 1	.84	71	39.5	o	S. W. 1	.70	50	39	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	calm	.87	61	39	o	calm	- -	- -	36	- -
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
12	S. E.	- -	- -	39	o	- - -	- -	- -	35	- -
	T. W. 39°.4.					T. W. 39°.0.				

	September 13.					September 14.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	- - -	- -	- -	37	- -	- - -	- -	- -	36	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	S. E. 2	29.75	54	37	- -	calm	29.90	50	37	c
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
Noon	- - -	.72	58	39	o	S. 1	30.12	59.5	38	b
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	S. E. 1	.65	55	39.5	o	S. W. 1	-	- -	40	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	N. by W.	- -	- -	36	- -	- - -	- -	- -	- -	- -
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
12	S. W.	- -	- -	34.5	s q	- - -	- -	- -	29	- -
	T. W. 38°.3.					T. W. 38°.0.				

	September 15.					September 16.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Wea-ther.
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	- - -	- -	- -	- -	- -	- - -	- -	- -	32	- -
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	N. W. 1	29.65	50	40	- -	calm	29.65	51	35	b
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
Noon	N. W. 1	.50	50	40.5	b	S. W. 1	.85	50	40	- -
2	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
4	- - -	- -	- -	- -	- -	N. W. 1	.92	47	38	o
6	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
8	S. by E.	.47	58	35	- -	calm	- -	- -	36	- -
10	- - -	- -	- -	- -	- -	- - -	- -	- -	- -	- -
12	S. by E.	- -	- -	34	- -	- - -	- -	- -	36	- -
	T. W. 37°.5.					T. W. 36°.6.				

Hour	September 17. Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	September 18. Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	- - -	- -	- -	- -	- -	calm	$29^{in}.40$	52°	37°	*o*	Sept. 17, 9½ A. M. Stood out of the harbor. At noon red beacon S. E. by S.; distance 4 miles.
4	- - -	- -	- -	34°	- -	S. E. 1	.45	56	39	"	
6	- - -	- -	- -	- -	- -	E.	.50	54	37	"	
8	S. E. 1	$29^{in}.72$	48°	35	- -	"	.60	59	35.5	"	
10	- - -	- -	- -	- -	- -	"	.50	50	37	"	
Noon	N.N.W. 1	.90	47	39	- -	"	.50	47	37	"	
2	N. 1	.50	45	37	*b*	E.N.E. 4	.40	48	36	"	
4	N. 2	.60	50	36.2	"	"	.35	47	37	"	
6	"	.50	52	36	*o*	E.N.E. 7	.50	45	35	"	
8	N.N.W. 1	.65	56	36	"	"	.45	50	35	"	
10	N.	.50	55.5	40	"	N. E. 8	.40	53	35	"	
12	calm	.45	53	39	"	"	.45	52	36	*s r*	
	T. W. 37°.0.					At noon lat. 68° 15′; long. 54° 53′ T. W. 36°.8.					

Hour	September 19. Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	September 20. Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	N. E. 8	29.50	50	35	*s r*	N. E. 5	29.70	46	35	*s*	Sept. 20. Water thermometer No. 2 broke; No. 12 substituted.
4	"	.50	49	35	"	"	.75	45	35	"	
6	"	.45	47	34	"	"	.70	44.5	35	*c*	
8	"	.40	49	32	"	"	.60	45.5	34.5	"	
10	"	.50	49	35	"	"	.50	47	35	"	
Noon	"	.45	50	36.5	"	"	.60	47	40	*c q*	
2	N. E. 7	.70	48	36	"	E.N.E. 4	.75	49	37	"	
4	"	.70	49	36	"	"	.78	50	35.5	*r*	
6	E.N.E. 6	.65	50	35.5	*o*	"	.70	50.5	36.5	*c*	
8	"	.60	49	37	"	"	.80	57	35	"	
10	N. E. 5	.55	50	35	"	"	.60	53	36	"	
12	"	.70	50	33	*c*	E.N.E. 5	.68	50	36	"	
	At noon lat. 64° 50′ by D. R. long. 56 25 T. W. 36°.1.					At noon lat. 62° 39′ long. 56 20 W. var. 59°; T. W. 39°.2.					

Hour	September 21. Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	September 22. Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	E. N. E.	29.60	50	36	*c*	N. N. E.	- -	- -	36	*c*	
4	E.N.E. 7	.55	50	37	"	"	- -	- -	36.5	*c q*	
6	E.N.E. 8	.60	50	37	"	"	29.70	51	36	"	
8	"	.60	50	37	*r*	N.	.60	55	36	"	
10	"	.75	50	37	"	- - -	.65	53	37	"	
Noon	"	.60	50	38	*c*	- - -	.70	50.5	37.5	*h*	
2	E.N.E. 7	.50	50	37	*o q*	N. 7	.60	50	37	*c*	
4	N. E.	.60	51	38	*c*	"	.70	50	37	"	
6	N. N. E.	.50	50	37	"	N. W. 6	.60	57.5	37	"	
8	E. N. E.	.70	54	37.5	"	"	.70	55	37	"	
10	N. N. E.	.65	54	37	"	N. 5	.70	54	37	"	
12	"	.75	54.5	37	"	"	.80	50	87	"	
	At noon lat. 59° 23′ by D. R. long. 55 00 W. var. 56°; T. W. 40°.9.					At noon lat. 56° 28′ long. 52 56 W. var. 44°; T. W. 40°.7.					

	September 23.					September 24.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	N.N.E. 4	29in.75	50°	38°	c	S. S. E. 5	30in.10	49°.5	43°	o	Sept. 23. At 3 P.M. passed an iceberg about 5 miles distant. Rainbow seen. Sept. 24. At midnight drifted past a small iceberg.
4	N N.E. 3	.72	53	37.5	"	"	.15	49	42	"	
6	"	.80	52	37.5	"	"	.00	50	42	"	
8	N.N.E. 2	.80	53	38	"	S. S. E. 7	29.90	50	37	"	
10	"	.90	54	39	"	"	.82	50	43	"	
Noon	N.N.E. 1	.90	54	43	"	S. S. E. 8	.88	54	46	o q	
2	N. E. 1	.90	51	43	c	S. S. E. 3	.90	51	46	f r	
4	E. by N. 2	.98	51	41	- -	"	- -	- -	- -	"	
6	E. by N. 3	.95	51	40	- -	W. 3	.80	48	43	c	
8	S. E. 3	30.00	52	40	o	N. W. 7	.60	50	41	"	
10	"	29.92	51	41	"	N. W. 8	.58	50	39	"	
12	"	30.00	50	43	"	"	.50	50	39	"	

September 23.	September 24.
At noon lat. 54° 42′ long. 51 48 W. var. 46°; T. W. 43°.7.	At noon lat. 53° 27′ by D. R. long. 52 24 W. var. 38°; T. W. 42°.7.

	September 25.					September 26.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	N. W.	29.70	50	42	c	W.N.W. 7	29.60	48	42	o
4	"	.60	50	40	"	"	.70	48	43	"
6	W.N.W. 8	.60	47	39.5	"	"	.75	48	41	"
8	"	.70	47	40.	"	"	.80	51	42	"
10	"	.75	48	41	"	W.N.W. 6	.70	50	40	"
Noon	"	.80	49	40.5	"	"	.70	50	40	"
2	"	.70	47	40	o	N. W. 6	.80	48	40	c
4	"	.80	47	40	"	W.N.W. 6	.90	52	40	"
6	"	.68	48	40.5	"	"	.85	57	39.5	"
8	"	.70	49	40	"	"	.80	54	39	"
10	"	.60	48	44	"	"	30.00	55	41	"
12	"	.60	47	43	"	W.N.W. 5	29.90	56	41	"

September 25.	September 26.
At noon lat. 52° 57′ by D. R. long. 51 45 W. var. 36°; T. W. 43°.3.	At noon lat. 52° 26′ by D. R. long. 51 12 W. var. 33°; T. W. 43°.4.

	September 27.					September 28.				
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.
2	W.N.W.	29.95	56	40	c	W. by N. 2	30.00	54	49	b
4	W.N.W. 3	30.05	54	42	"	"	.90	54	47	"
6	W.	29.90	54	43	"	"	.98	53	47	c
8	S. W.	30.00	53	43	"	"	.95	53	47	"
10	W. by S.	.02	51	46.5	"	W. by S. 2	.90	53	48.5	"
Noon	W.	29.96	52	47	"	"	30.05	53	49.5	b
2	W. 3	30.15	54	50	b	W.	.10	54	54	c
4	W. by S.	.10	52	51	"	"	29.95	56	51	- -
6	W. 2	.10	54	50	"	W.S.W. 2	30.02	54	52	c
8	"	29.98	54	50	"	var.	.10	54	50	- -
10	"	.95	55	47	c	W. by S.	.20	58	50	b c
12	"	.90	54	46	r	"	.20	58	48	- -

September 27.	September 28.
At noon lat. 49° 5′; long. 48° 55′ W. var. 33°; T. W. 47°.3.	At noon lat. 47° 42′; long. 48° 5′ W. var 33°; T. W. 46°.4.

	September 29.					September 30.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	W.S.W. 2	$29^{in}.95$	57°	50°	*f*	N.W.byW.	$30^{in}.05$	61°.5	54°	*c*	
4	"	.98	58	50	"	N. N. W.	.10	59	54	- -	
6	W. by S.	30.05	58	51.5	- -	"	.00	50	53	*f*	
8	W. by S. 2	.95	56	53	*f*	"	.00	54	54	*c*	
10	W.S.W.	30.00	58	54	"	N.N.W. 3	.00	53	50	*b*	
Noon	"	.10	57	55	"	"	.05	52	48.5	"	
2	W. 3	29.90	59.5	56	"	N.N.W. 2	.15	52	48.5	*c*	
4	W. by S. 3	30.00	58	56	"	"	.20	54.5	50	"	
6	S.W.byW.	.10	59	56	*r*	N.W.byW.	.00	55	50	"	
8	"	.20	62	56	"	N. W. 2	29.95	55	51	"	
10	W.S.W. 2	.15	61.5	55	"	N.W.byW.	30.05	56	50	- -	
12	W. by S. 2	.10	52	55	*o*	N. W. 2	.10	55.5	50	- -	
	At noon lat. 47° 19′ by D. R. long. 49 27 W. var. 30°; T. W. 50°.7.					At noon obs'd lat. 46° 54′ " long. 50 39 W. var. 27°; T. W. 51°.6.					

	October 1, 1861.					October 2.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	N.W.byN.	30.00	55	50	*b c*	N.W.byW.4	30.24	55	51	*c*	Oct. 1. At noon cast of lead gave 43 fathoms, gravel and gray sand. Oct. 2, 8 A. M. Spoke brig "Liverpool," 2½ P.M. spoke Eng. ship "Robert Parker."
4	"	.00	54	50	"	"	.10	55	51	"	
6	N.N.W. 4	29.90	53	47	*c*	"	.05	56	53	"	
8	N.N.W. 3	30.10	53	48	*b*	N. W.	.10	57	53	"	
10	N.	.15	52	49	"	N. W. 3	.00	54	53	"	
Noon	"	.20	53	49	*c*	"	.00	55	53	"	
2	N. N. W.	.00	54	48	"	W.N.W. 4	.08	59	57	"	
4	- - -	.00	52	48	"	N.W.byW.6	.20	59	56	- -	
6	var.	.23	52	48	"	N. N. W.	.05	58	55	- -	
8	N. W.	29.95	55	49	"	N.W.byN.	.10	58	56	*c*	
10	N. N. W.	30.10	55	52	*q r*	N. 2	.16	60	55	"	
12	"	.10	55	52	- -	"	.20	60	55	"	
	At noon lat. 45° 21′ by obs'n long. 52 36 W. var. 25°; T. W. 55°.1.					At noon lat. 44° 2′ by obs'n long. 53 55 W. var. 27°; T. W. 58°.9					

	October 3.					October 4.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	N.	30.25	60	55	- -	S. W.	29.90	68	63	*r q l*	
4	N. 1	.20	60	54	- -	W. by N.	.80	67	63	"	
6	calm	.10	61	53	*o*	W. by N. 3	30.00	65	61	*b*	
8	S. S. E.	.00	60	54	*c*	W.N.W. 2	.05	64	59	"	
10	S. W. 2	29.90	59	59	"	"	.10	62	56	- -	
Noon	S. W. 4	.88	62	62	*o*	"	.05	62	59	- -	
2	S.W.byS.4	.85	64	62	*r q*	N. W.	29.90	61	63	*o*	
4	S. W. 3	.95	67	63	*b c*	"	.90	61	63	"	
6	W.S.W.	.90	67	64	*o*	N.N.W. 4	.82	60	55	"	
8	W.S.W. 4	.95	70	64	*c*	N.W.byW.	.95	60.5	55	*r*	
10	W.S.W. 2	30.05	70	64	*b*	N. by W.	.80	57	52	"	
12	"	29.98	69	63	"	"	.80	57	52	- -	
	At noon lat. 43° 35′ by D. R. long. 55 02 W. var. 26°; T. W. 62°.7.					At noon lat. 44° 18′ by obs'n long. 55 00 W. var. 26°; T. W. 59°.8.					

	October 5.					October 6.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	N. 3	29in.73	56°	53°	c	N. E. 1	30in.25	57°.5	51°	c	Oct. 6, 5½ P. M. Kept away for Halifax, being unable to carry head sail, having no spars on board to repair damages.
4	"	.80	55	52	"	S. E. 1	.30	58	52	"	
6	N. by W.	.85	54	52	- -	"	.30	58	53	"	
8	"	.80	55	51	c	E. S. E.	.30	59	54	r	
10	"	.80	54	52	o	S. 4	.20	59	59	c	
Noon	"	.80	54	51	"	"	.28	63	61	"	
2	N. by W. 4	30.10	54	52.5	c	S. by W. 4	.25	68	62.5	"	
4	"	.15	55	51	"	S. S. W.	.30	67	64.5	"	
6	"	.20	55	50	- -	"	.20	67	64	o	
8	"	.10	56	49	- -	S. W. 4	.40	66	65	"	
10	N.N.E. 3	.30	56	51	c	"	.10	65.5	64	b	
12	N. E. 2	.35	57	51	"	"	.20	62	63.5	"	

October 5. At noon lat. 43° 27′ by obs'n
long. 56 51
W. var. 23°; T. W. 58°.8.

October 6. At noon lat. 43° 05′ by D. R.
long. 59 28
W. var. 22°; T. W. 63°.4.

	October 7.					October 8.					
Hour	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	Wind D. and F.	Bar.	Att. ther.	Temp. air.	Weather.	
2	- - -	30.30	65	61	b	calm	30.24	63	61	f	Oct. 7, ½ P.M. Spoke bark "Regina." 4 P. M. No bottom with 65 fathoms. 8 P. M. No bottom with 65 fathoms. 10 P.M. by alt. of Polaris lat. 44° 4′. Cast lead; no bottom; 65 fathoms. Oct. 8, 2 A.M. No bottom with 60 fathoms. 11 A.M. in 42 fathoms water, coral, gravel, & shell. 0h 25m P. M. Dense fog; made the land bearing N.W. by W. ¼ of a mile distant.
4	S.W. by S.5	.20	62	58	"	"	.05	64	60	o	
6	"	.30	64	62	"	E.	.10	65	60	"	
8	"	.25	65	63	"	W. by S.	.15	64	58	f	
10	"	.20	67	64	"	E.	.10	63	58	"	
Noon	W.S.W. 5	.30	66	65	o	E. 2	.00	63	58	"	
2	S. W.	.20	66	63	f	E. S. E. 2	.10	62	58.5	"	
4	"	.20	65	62	"	"	.06	61	57	"	
6	W. by S. 2	.20	65	61	"	S. by E.	.10	62	59	"	
8	W.S.W. 1	.15	63	60	"	S. S. W. 3	.10	63	60	"	
10	"	.20	62	60	"	"	.08	65	60	"	
12	"	.20	65	60	b	"	29.82	65	60	r	

October 7. At noon lat. 43° 45′ by D. R.
long. 63 20
W. var. 22°; T. W. 59°.5.

October 8. At noon lat. 44° 05′ by D. R.
long. 64 31
W. var. 1½ pts.; T. W. 57°.9.

	October 9.					
Hour	Wind D. and E.	Bar.	Att. ther.	Temp. air.	Weather.	
2	N.N.W. 3	29.85	61.5	61	r	Oct. 9, 6 A.M. Took pilot on board; entered Halifax Harbor; at anchor until Oct. 19.
4	N.	.90	60	60	"	
6	"	30.00	60	56	"	
8	N. E. 3	29.90	60	52	c	
10	"	.85	61	53	"	
Noon	"	30.20	57	52.5	"	

T. W. 56°.7.

1861. October 19. 1 P. M. Stood out of the harbor.
20. At noon lat. 43° 14′ by obs'n; long. 61° 32′
21. " " 41 58 " " 66 22
22. " " 42 17 " " 69 27

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